LARGE CULVERT STUDIES IN MONTANA

Prepared for
Montana Highway Commission
Planning Survey Section
in cooperation with
U. S. Department of Transportation
Bureau of Public Roads

ENGINEERING

Research Laboratories

MONTANA STATE UNIVERSITY, BOZEMAN

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by

Alfred C. Scheer

Associate Professor

Department of Civil Engineering and Engineering Mechanics

Montana State University

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ABSTRACT

In the summer of 1963, approximately 400 large culvert installations in Montana were given brief inspections for the purpose of identifying functional and structural problems. This was the initial phase of the large culvert research project reported in this paper. Most of the culverts inspected were structural plate steel highway culverts of seven-foot diameter or larger. Fifty-five of the culverts were selected for intensive study which extended over a period of five years.

Observed cases of embankment erosion, channel scour, sedimentation, abrasion, corrosion, and structural distress, were investigated. The investigations covered a relatively wide range of topics and led to numerous conclusions and recommendations concerning the design, construction, and maintenance of large culverts and their appurtenances.

The most serious type of soil erosion encountered and studied was internal erosion by seepage water which leads to the formation of large empty piping channels alongside or beneath affected culverts. Piping may cause a catastrophic structural collapse or a total washout of a culvert.

A serious type of structural distress, encountered in some structural plate culverts, was cracking of the plates along bolted seams. These were bending failures which usually occurred in conjunction with excessive deflections resulting from insufficient lateral support from the adjacent backfill soil.

Backfill condition studies were conducted using Schmidt Hammer rebound readings taken on the inside walls of structural plate culverts. The Schmidt Hammer readings were found to correlate fairly well with backfill condition as determined by punching holes in the wall and probing with a wire. Pilot experiments with nuclear moisture - density meters were also conducted, inside two culverts, and the results suggest that a meter could be developed to accurately measure backfill soil density and moisture content right through metal culvert walls.

The last chapter of the report deals with the subject of periodic inspection of large culverts and contains detailed recommendations for conducting annual or biennial inspections of large culvert installations, on a state-wide basis.

ACKNOWLEDGEMENTS

Mr. Harvey D. Funk, currently City Engineer of Glendive, Montana, merits special recognition for the outstanding work that he did on the project as the writer's chief assistant between June of 1963 and June of 1966. Harvey started on the project as an undergraduate student assistant and continued as a graduate research assistant until the summer of 1966 when he completed the requirements for the Master of Science Degree in Civil Engineering. During that time he personally performed a major share of the field and office work and supervised the work of several other student assistants.

The writer is also grateful for the large amount of assistance furnished by personnel of the Montana State Highway Department; with special thanks going to Messrs. Leroy Hargrove, Don Gruel, Howard Buswell, and Paul DeVine, for sustained help and counsel extending over a period of several years.

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Bureau of Public Roads.

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CHAPTER I

INTRODUCTION

The large Culvert Research Project at Montana State University started in June of 1963 and continued through 1967 under the sponsorship of Montana Highway Commission and the Bureau of Public Roads.

The prospectus for the project was entitled "An Investigation of Large Culvert Installations in Montana, Especially with Regard to the Functional Adequacy of Inlets and Outlets"; and the early thinking regarding the scope and goals of the project was succinctly set forth in the last paragraph of the prospectus abstract which is quoted below:

> "It is proposed to make a detailed survey and analysis of large culvert installations in Montana. The study would be limited to about 50 of the largest culverts in the state and would be concerned primarily with the problems of scour, sedimentation, and flooded flow hydraulics. The information obtained should serve as a basis for review of current design and construction practices, especially those dealing with the problem of erosion prevention."

From the start, there was no intention of selecting culverts for study on a random basis. It was deemed more fruitful to seek out and study culverts with less than ideal performance histories, or culverts with unique features of some sort that made them objects of special interest. It was also decided to pay particular attention to culvert installations between four and eight years of age on the theory that these culverts would be old enough to have developed some visible evidence of deficiencies but young enough to make the findings relevant to current practice.

It was also agreed to limit the study primarily to corrugated steel structural plate culverts of seven foot size or larger; however, three reinforced concrete pipe culverts of special interest were included in the study.

In the spring and early summer of 1963, the Montana State Highway Department furnished project personnel with a list of approximately 200 large culverts, most of which had been installed between 1955 and 1959. A few of the culverts on the list were there by virtue of having been recommended for study by district or division highway engineers or engineers from the highway department headquarters in Helena. The only part of the state not represented on the list was northwestern Montana which was omitted because it had, ostensibly, fewer culvert problems than other parts of the state.

During the summer and early autumn of 1963, the culverts on the list, plus at least an equal number not on the list, but encountered while traveling to inspect the others, were briefly inspected for signs of inadequacies or other features of special interest sufficient to justify a more detailed survey.

Out of the 400 or more culverts thus briefly inspected, 55 were singled out for a detailed study. Most of this report deals with this select group of 55 culverts.

Early in the study it was found that some culverts in the state had serious problems not directly related to scour, sedimentation, or flood flow hydraulics. The scope of the study was broadened somewhat to include these other types of problems.

The extreme difficulty encountered in trying to get to the right places at the right times, to photograph culverts during floods and study their flood-flow hydraulics, resulted in a very small amount of data collected on this subject. Early in the history of the project, steps were taken to enlist the aid of district or division highway personnel to take pictures of culverts carrying flood runoff, but it turned out that they also found it virtually impossible to be at the right places at the right times. Over a two year period, so little data was gathered on the subject that the early hope of studying flood flow hydraulics had to be abandoned.

Early in 1965 the project was extended and expanded to include instrumentation and study of the structural behavior of the rebuilt Wolf Creek culvert. This culvert, 25 miles north of Helena on Interstate Route 15, failed in 1964 and was rebuilt in 1965. A separate report will be written on this one culvert so no further mention of it will be made in this report.

Only a small percentage of the culverts inspected showed evidence of serious distress. Soil erosion at the outlet, and/or the inlet, was observed frequently; but problems of sedimentation, abrasion, and corrosion, were fewer than anticipated.

The most serious type of soil erosion encountered was internal erosion by seepage water which had eroded piping channels through the embankment at some culvert sites. Structural distress was also observed in some culverts, with cracking of the plates along bolted seams being the most prevalent type observed during the culvert inspection trips.

CHAPTER II

THE CULVERT INSPECTIONS AND SURVEYS

Starting in late June, 1963, the project supervisor and one assistant undertook a series of inspection trips to examine the large culverts on the list of approximately 200 furnished by the Montana Highway Department. Approximately an equal number which were not on the list, but which were encountered while traveling to or from the others, were also briefly examined. These quick inspections usually required no more than 30 minutes at a culvert site, and consisted primarily of systematic visual observations to check for the presence or the extent of channel scour, fill erosion, undermining, piping, sediment deposits, abrasion, corrosion, excessive deformation, cracked plates, or any other signs of distress that might be present. Unless high water or mud in the culvert prevented it, part of the inspection was conducted from inside the culvert and usually entailed a walk through the culvert from one end to the other.

In most cases, the approximate location of each inspected culvert was marked in a book of county road maps, along with brief notes relating to the observed condition of the installation.

It was fortunate that some of the first culverts inspected suffered from unanticipated problems, including piping and cracked plates. This alerted project personnel to look specifically for these serious but unobtrusive problems in all culverts subsequently inspected. A conscientious culvert inspector could easily overlook certain inconspicuous signs of trouble unless

he had prior knowledge of what he should look for, and where.

When a culvert with a serious problem was encountered, it was usually singled out for a detailed survey and included as one of the "project culverts"' a group which eventually grew in number to include 55 installations.

One of the detailed surveys usually required somewhere between two and six hours to complete. In some cases, it was conducted on the same day that the culvert was first inspected; in other cases, it was conducted on a subsequent trip.

During the first couple of weeks of culvert inspections and surveys, a set of six field data sheets were developed for use on subsequent surveys. Appendix A shows a set of these data sheets, filled out for one of the project culverts.

Sheet 1 was essentially a visual inspection data sheet which was filled out during the course of a careful and deliberate visual inspection. Liberal space was reserved for notes near the bottom of the page.

Sheets 2 and 3 were snapshot survey data sheets designed to facilitate the collection and preservation of a meaningful pictorial record of each installation. A simple plan view of the installation was sketched on sheet 2. Then the approximate location of the camera, and the direction it was aimed, for each numbered snapshot, was indicated on the sketch by an encircled numeral and a directional arrow. The usual snapshot survey included at least one shot each of the upstream and downstream channels, as viewed

from the roadway; shots of the inlet and outlet from various vantage points; and shots of any special features that were deemed to be of interest. Notes intended primarily for orientation and reminders, when viewing the pictures at a later date, were entered on sheet 3 for each snapshot.

Most of the camera work was done with a high quality 35 mm. camera, using black and white film. Some color slides were taken of special interest features.

Sheet 4 was a Schmidt Hammer survey data sheet used to record Schmidt Hammer readings that were taken against the culvert walls inside most of the structural plate culverts as part of a systematic search for empty space or loose fill behind the plates. In general, low readings were indicative of soft or loose fill, or empty space behind the plates.

Sheet 5 was a data sheet for recording the notes for a set of profile levels that were run through each culvert and along the upstream and downstream streambed.

Sheet 6 was a data sheet for recording culvert barrel measurements, sediment depths, heights of cover, and related measurements made with a tape, rod or hand level.

A study of these six data sheets in Appendix A will acquaint the reader with the extent of the surveys that were conducted on the 55 project culverts during the summer and autumn of 1963. A follow-up inspection was conducted on each culvert in the summer of 1964 to gather additional data and to look

for changes that may have occurred during the intervening year.

An important part of the 1964 surveys was the punching of holes in the walls of many of the culverts to trace out zones of empty space, and to establish the relationship between Schmidt Hammer readings and backfill condition for different plate thicknesses and different locations within a culvert.

Soil samples for laboratory analysis were also taken at most of the culvert sites in 1964, if they had not been taken the previous year.

Follow-up inspections in 1965 and 1966 were limited to a selected few of the project culverts that had features of special interest. A final inspection of 45 of the project culverts was made in June and July of 1967.

Certain culverts not numbered among the 55 project culverts, but having certain special interest features in common with some of the project culverts, were also studied in the course of certain investigations that grew out of the surveys.

To supplement the large quantity of field data gathered on each culvert, project personnel also procured "as-built" plans and construction notes for most of the project culverts from Highway Department headquarters in Helena.

Conversations were held with district and division highway engineers to gather additional information on the project culverts. Also, division maintenance men were interviewed to gather as much information as possible about

the maintenance history of each culvert. Most of the information furnished by the persons interviewed was a matter of personal recollection based on their memories of places and events.

Location and identification data on the 55 project culverts, and a condensed summary of the culvert survey findings, are given in tabular form in Appendix B of this report.

Topics warranting detailed consideration and discussion are covered in the following chapters. Some of the topics are not closely related to each other and have, therefore, been treated as semi-independent units within the report, each having its own set of conclusions and recommendations.

CHAPTER III

SURVEY FINDINGS

Most of the project culverts were selected for detailed study because they exhibited characteristics or problems from which it was thought important lessons might be learned.

Soil erosion at the outlet, usually involving some degree of embankment erosion and undermining of the outlet, was the problem most frequently encountered. In some cases the erosion was accompanied by degradation of the outlet channel, a potentially very serious condition which will be considered following the more common situation where the erosion does not extend downstream beyond the boundaries of a well-defined scour hole.

SCOUR HOLES WITHOUT DOWNSTREAM CHANNEL DEGRADATION

Twenty-one of the project culverts[1] had outlet scour holes, without evidence of downstream channel degradation. For approximately half of this group, the scour holes were of minor significance, being no more than two feet in depth and showing little or no adverse effect on either the culvert installation or the adjacent terrain.

Four of the larger and deeper scour holes photographed in 1963 are shown in Figures 1 through 4. The hole shown in Figure 1 was subsequently filled with riprap, and there was little visible sign of the former outlet scour

[1]Project culverts nos. 2, 5, 6, 8, 9, 13, 16, 20, 30, 31, 32, 33, 38, 39, 45, 46, 48, 49, 51, 52.

problem when the installation was last inspected in July of 1967. The scour holes shown in Figures 2, 3 and 4, did not experience any significant changes between 1963 and 1967.

Undermining of the outlet and erosion of the adjacent embankment frequently occur at outlet scour holes unless the outlet is protected by a cutoff wall and/or adequate riprap. Most of the project culverts were installed before cutoff walls and riprap protection became standard requirements on large culvert installations in Montana. The outlet protection now used on new installations will, in most cases, prevent or greatly reduce undermining and embankment scour of the type shown in Figures 1 through 4.

Outlet scour holes are usually quite harmless, if outlet protection is adequate to prevent embankment erosion and culvert undermining, and if there are no nearby man-made "improvements", such as fences or irrigation structures, which the scour hole might endanger.

An outlet scour hole may be beneficial to the extent that it provides a place for the safe and natural dissipation of the potentially dangerous erosive energy commonly possessed by water emerging from a culvert during periods of heavy flow. It is ideal if all of this excess energy can be dissipated harmlessly within a few feet of the culvert outlet so that it does not degrade the downstream channel and form a deep and unstable gully of great length.

Keeley (1)[1], in a study of culvert outlet conditions in Oklahoma, has

[1]Numbers in parenthesis refer to papers listed under LITERATURE CITED.

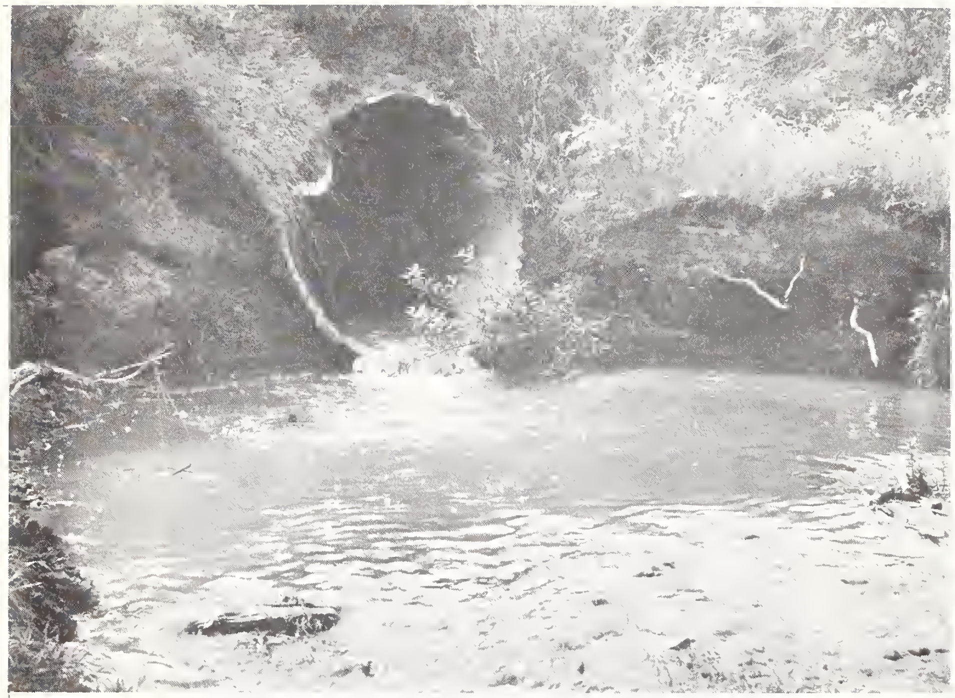


FIGURE 1. OUTLET SCOUR HOLE AT PROJECT CULVERT NO. 5

FIGURE 2. OUTLET SCOUR HOLE AT PROJECT CULVERT NO. 8

FIGURE 3. OUTLET SCOUR HOLE AT PROJECT CULVERT NO. 45

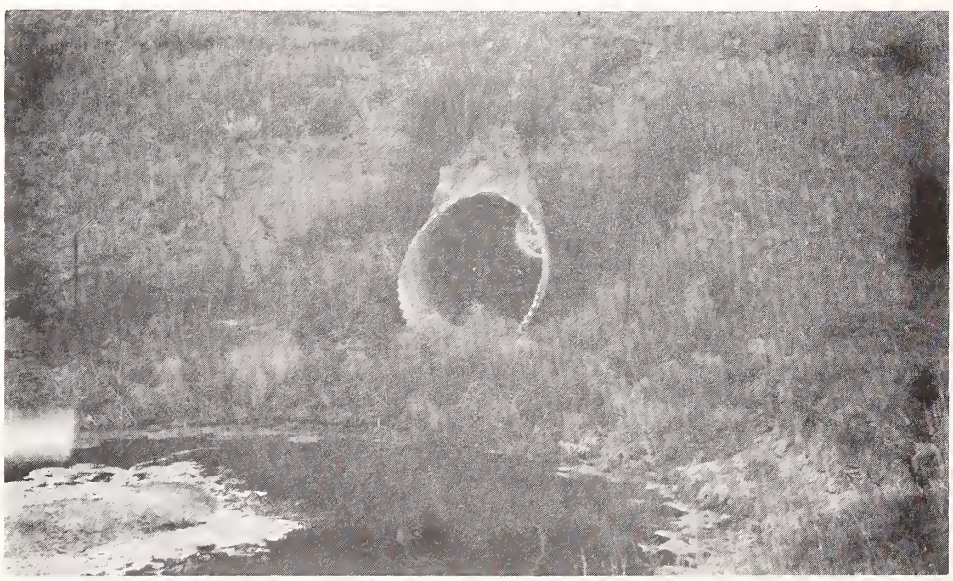


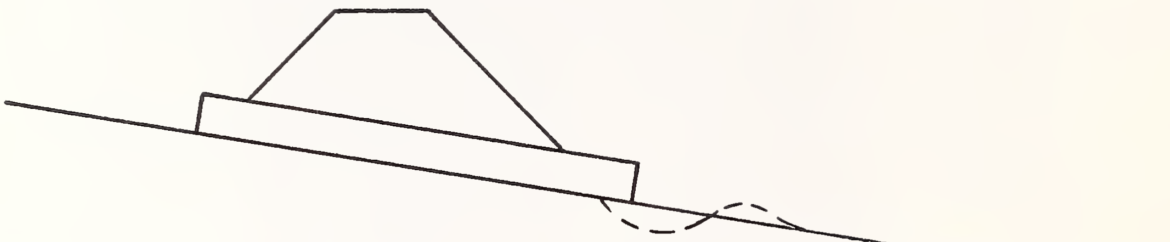
FIGURE 4. OUTLET SCOUR HOLE AT PROJECT CULVERT NO. 52

concluded that a scour hole is an excellent natural energy dissipator. He states:

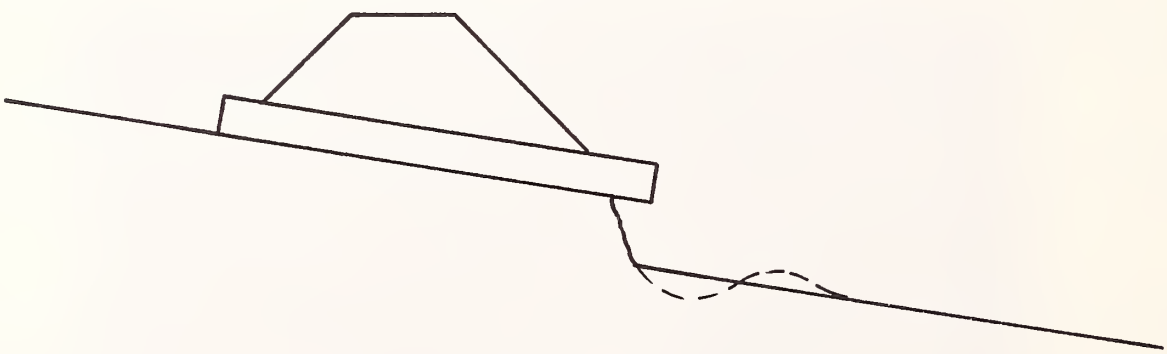
> "At the beginning of a storm the basin will fill with water which, by dispersal and inertial resistance, absorbs the excessive kinetic energy of the high velocities emerging from the outlet. To fill the hole with broken concrete or car bodies is unnecessary as a maintenance measure and serves, usually, to reduce the efficiency of the basin."

It is not always apparent, by visual inspection, whether or not channel degradation has occurred downstream from a culvert. However, when a culvert-streambed profile is plotted, the appearance of the profile will usually permit an accurate judgment to be made. The difference in profile, between an undegraded and a degraded channel, is illustrated in Figure 5.

Streambed profile levels, taken as part of the large culvert surveys, were plotted on graph paper. Downstream channel profiles of the type illustrated in Figure 5 (a) were then classified as stable, and those of the Figure 5 (b) type were classified as degraded. It is possible that a few channels were wrongly classified as stable because the profile levels were seldom carried more than 200 feet beyond the outlet. It is recognized that channel degradation may start at a control station located many hundreds of feet downstream from the culvert, and gradually work upstream to the culvert outlet.



(a) Undegraded downstream channel, with or without scour hole



(b) Degraded downstream channel, with or without scour hole

FIGURE 5. TWO TYPES OF DOWNSTREAM CHANNEL PROFILES

DEGRADATION OF THE OUTLET CHANNEL

Seven of the project culverts[1] exhibited downstream channel degradation, with a streambed profile like that of Figure 5 (b). In three of these cases, the depth of channel degradation was less than 2-1/2 feet and the erosion damage appeared to be of little consequence. However, the remaining four[2] showed pronounced erosion damage. Pictures of the outlets and downstream channels of all four of these installations are shown in Figures 6 through 13.

One condition that is known to promote channel degradation is the concentration, into one narrow channel, of a flow that previously spread out over a broad area. A slight amount of channel degradation observed at project culvert No. 21 appears to be attributable to this condition. Upstream from the culvert is a broad swale with no clearly defined channel. Concentration of flow also occurs when the flow from two or more channels is diverted into a single channel. It is rather surprising that more cases of channel degradation caused by concentration of flow were not observed in the course of the large culvert surveys. Perhaps the problem is more prevalent at small culverts than at large ones.

[1] Project Culverts 1, 21, 23, 25, 27, 40, 41

[2] Project Culverts 1, 25, 40, 41

FIGURE 6. OUTLET OF CULVERT NO. 1
Most of the large rocks were placed in the channel in attempts to provide scour protection.

FIGURE 7. DEGRADED OUTLET CHANNEL OF CULVERT NO. 1, TERMINATING IN THE YELLOWSTONE RIVER
Notice undermining of fence post on left and trees on right.

FIGURE 8. OUTLET OF CULVERT NO. 25
Note partial failure of grouted riprap outlet protection.

FIGURE 9. DEGRADED DOWNSTREAM CHANNEL OF CULVERT NO. 25
Note riprap dam in outlet channel.

FIGURE 10. OUTLET OF CULVERT NO. 40
Note partial failure of grouted riprap.

FIGURE 11. DEGRADED OUTLET CHANNEL OF CULVERT NO. 40
Remnants of a grouted riprap outlet apron are visible in the picture.

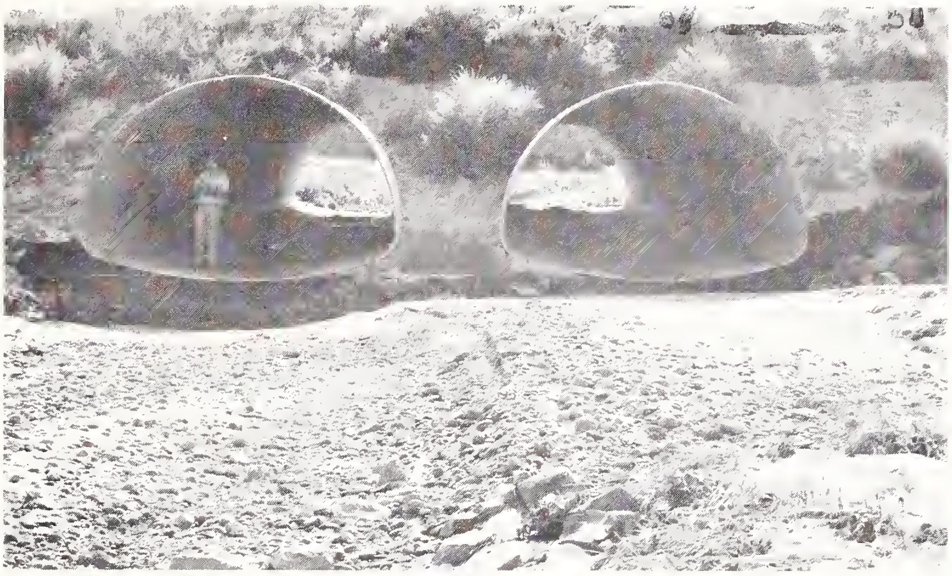


FIGURE 12. OUTLET OF CULVERT NO. 41
A grouted riprap outlet apron has been completely washed away.

FIGURE 13. OUTLET CHANNEL OF CULVERT NO. 41
The channel degradation is not severe in this case.

At six out of the seven large culvert sites where channel degradation was observed, it was apparent that channel changes had been made at the time of construction. These included project culverts Nos. 25, 40 and 41, shown in Figures 8 through 13. At all three of these installations, the design engineers anticipated scour trouble and the outlets were provided with grouted riprap outlet aprons. In each of the three cases, however, the outlet aprons were destroyed, presumably by undermining as channel degradation worked its way inexorably upstream. It is recognized that frost heave and high pore water pressure under the aprons were two additional factors that may have contributed to the failures.

The reason why channel degradation is frequently associated with channel changes is easy to understand when one recognizes that the typical channel change provides a shorter and straighter channel on a slope that is usually much steeper than the equilibrium slope of the original channel. In the usual case, the natural channel slope is an equilibrium slope. If soil conditions are the same in the old channel and the new, then one should expect that the flowing water in the new channel will degrade it down to an equilibrium slope which will be at least as gentle as that of the original channel.

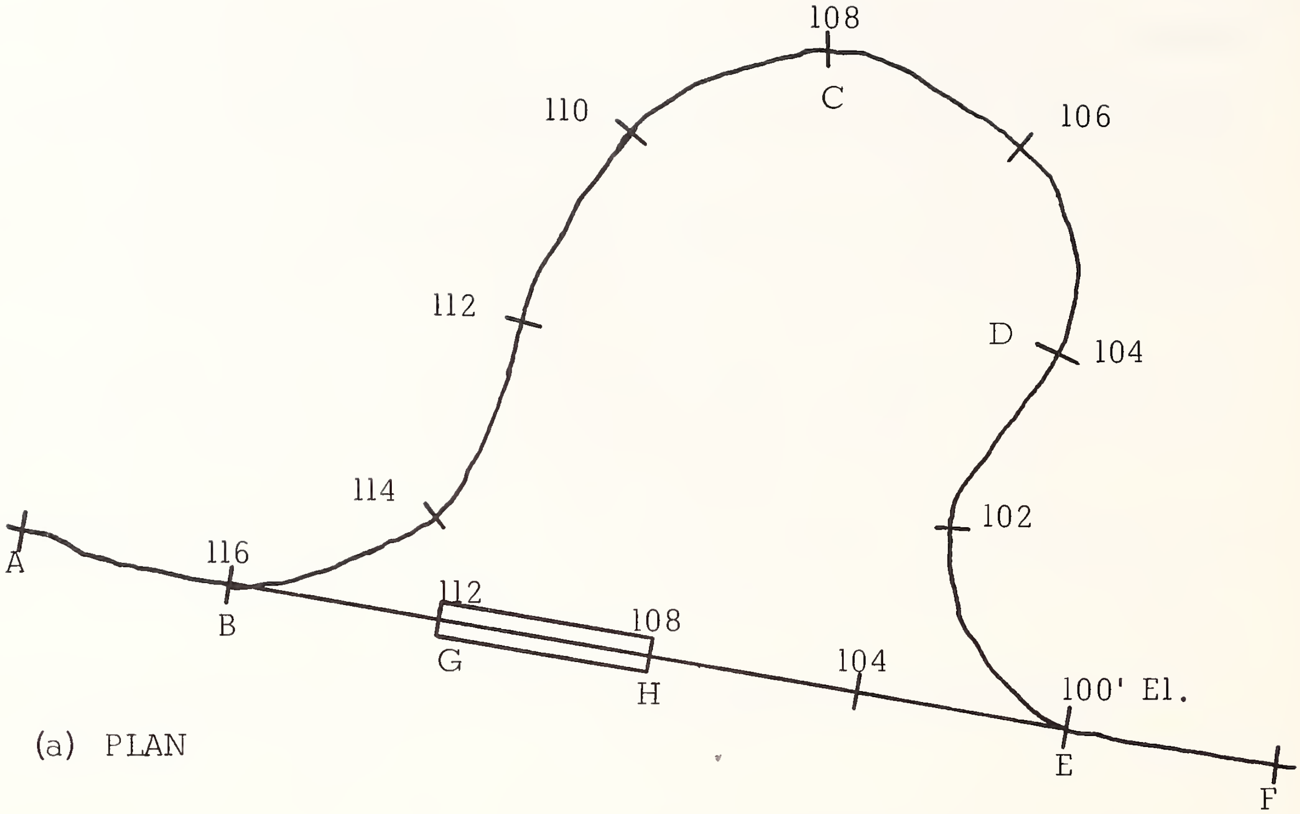
Channel degradation typically works its way upstream from a control point. In the case of a simple channel change, the control point may be at or near the lower end of the channel change where the unnaturally steep new

channel meets the flatter and ostensibly stable downstream channel. At an intermediate stage of its degradation, the upper portion of a straightened channel may still be much steeper than the equilibrium slope while a lower portion has already been reduced to an equilibrium or near-equilibrium slope. The transition between the two sections is likely to be very abrupt--perhaps a single vertical waterfall which eventually cuts its way upstream to the culvert outlet which it promptly undermines unless the outlet is protected by a cutoff wall of sufficient depth to prevent undermining.

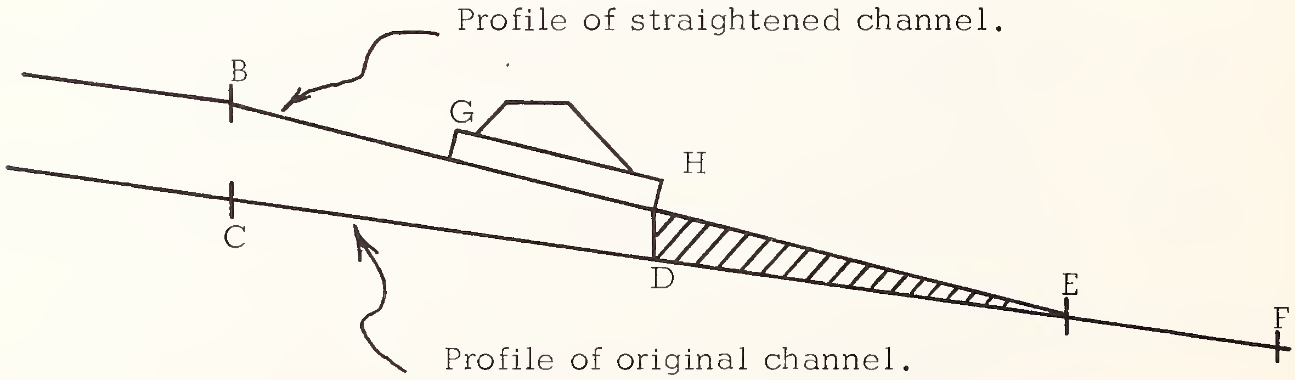
A quantitative estimate may easily be made of the least depth of outlet scour attributable to a channel change. The following numerical example illustrates the procedure.

In Figure 14 (a), ABCDEF represents a natural channel on an equilibrium slope of two percent. Bed elevations at 100 foot stations are shown. BGHE represents a 400 foot long channel change which replaces 800 feet of the original channel BCDE. GH represents a 100 foot long culvert installed in the new channel, with inlet and outlet elevations of 112 feet and 108 feet.

The normal discharge, flowing faster than normal down the steep slope HE, will proceed to cut the outlet channel back down to an equilibrium grade of two percent or less. In this case one should expect the equilibrium elevation of the outlet channel at H to be no higher than the elevation of station D in the original channel, namely 104 feet. The 4 foot difference in elevation between H and D thus becomes the minimum expected depth of scour at the



(a) PLAN



(b) PROFILE

FIGURE 14. PLAN AND PROFILE OF AN IDEALIZED CHANNEL CHANGE

culvert outlet. The shaded zone HDE, on the profile, portrays the minimum expected scour pattern between the culvert and station E.

The anticipated scour of the preceding example would be expected on the basis of the single fact that the slope of HE in the new channel is greater than the slope of DE in the old channel. Other factors that could aggravate the situation, and cause additional scour in the outlet channel, are concentration of flow, effected by a narrow culvert, the abnormally steep slope between B and H, and a relatively smooth culvert. All three of these factors would tend to increase the velocity and the scour potential of the water emerging from the culvert.

It should be pointed out that, in the preceding example situation, the channel upstream from the culvert will also be degraded back to a uniform two percent slope extending upstream indefinitely from the 112 foot control elevation at G. Thus, the entire channel upstream from B will theoretically scour out to a new equilibrium position that is two feet lower than its original equilibrium position unless strata possessing increased erosion resistance are encountered at a higher elevation, or unless the stream lengthens its upstream channel by new meanders which bring it back to the equilibrium slope without the need for any further vertical scour or degradation of the bed.

Figures 15 and 16 show the outlet situation at project culvert No. 26, which was placed in a straightened channel similar to that of culvert No. 25 shown in Figure 8. The absence of outlet channel scour at culvert No. 26

FIGURE 15. OUTLET OF CULVERT NO. 26
A natural sandstone "ditch check" is visible in foreground.

FIGURE 16. OUTLET CHANNEL OF CULVERT NO. 26
A series of sandstone dikes form natural ditch checks which effectively prevent degradation of the straightened channel.

may be attributed to a series of erosion-resistant parallel sandstone dikes which cut across the outlet channel and form a series of near-perfect natural ditch checks.

It is possible to avoid or at least minimize outlet channel degradation, when a culvert is placed in a straightened channel, by cutting the new channel down to the equilibrium slope right at the start. For instance, referring back to Figure 14, if the new channel were excavated on a two percent slope all the way from E to B the culvert outlet would then be four feet lower, with H at the same elevation as D. This would eliminate or reduce the outlet channel degradation problem but it would intensify the scour problem upstream from the culvert where an eight foot high waterfall would now exist near station B. This dilemma could be avoided by extending the channel change upstream on a meandering alignment until it could be connected back into the original channel without any elevation or slope difference. If a channel change were effected in this manner, the length and slope of the new channel would be the same as the length and slope of the old channel.

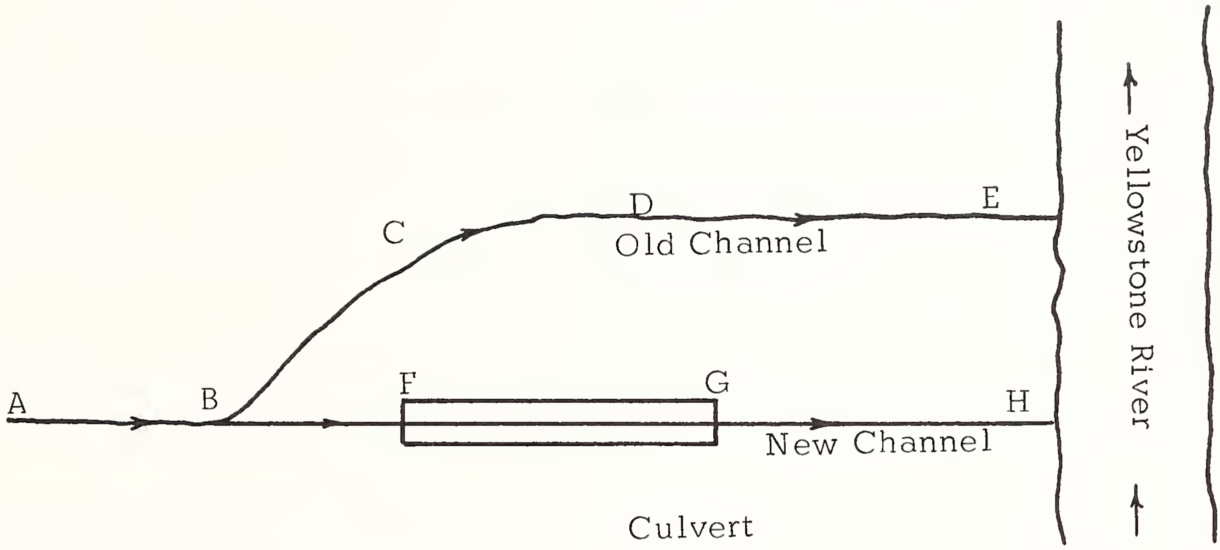
E.W. Lane has written a brief and easy to read paper (2) which is recommended to anyone who wishes to gain some valuable fundamental insights into the problems of channel degradation and aggradation that may arise as a result of upsetting the equilibrium of a stream in any one of a number of different ways. Engineers who are not channel stability experts, but who must make decisions on matters that may profoundly affect channel stability, will find Lane's paper to be especially worth while.

The outlet channel scour observed at project culvert No. 1, on Eight-Mile Creek, and visible in Figures 6 and 7, could have been predicted using the same principles discussed earlier. Eight-Mile Creek, which empties into the Yellowstone River only 100 feet downstream from the culvert, had a slope of about four percent before installation of the culvert.

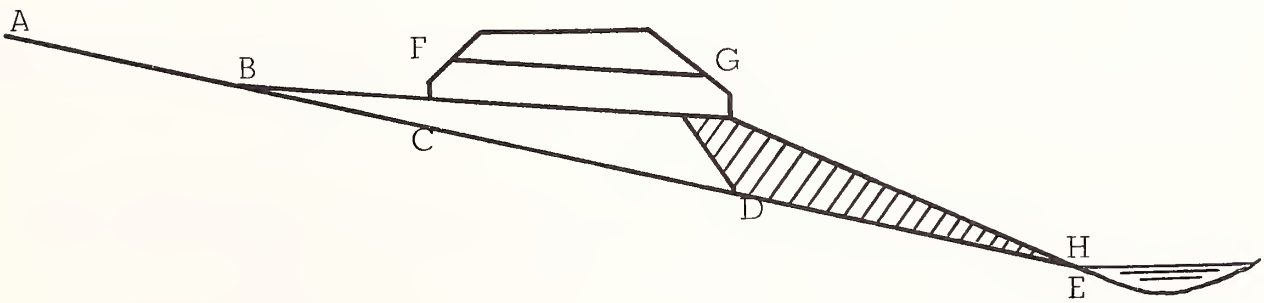
Figure 17 is a schematic plan-profile sketch of the installation. The culvert was installed in a rather minor channel change, but it was installed with the outlet invert G about 3-1/2 feet higher than the corresponding point D in the original channel. This gave the new outlet channel GH a slope that was almost double that of the original channel DE. Gully scour in the outlet channel degraded it down to a profile which almost coincided with that of the original channel DE in spite of attempts to halt the scour by dumping large rocks in the outlet channel. Undermining of this culvert, and related problems which will be discussed later in this report, brought it to a state of incipient structural collapse. It was replaced in the summer of 1967.

The apparent reason for installing the culvert high in the first place was to minimize both the required length of the culvert and the required amount of excavation. It appears that the practice of installing culverts high is seldom worth the risk and should usually be strongly discouraged.

The outlet scour problem at project culvert No. 25, shown earlier in Figures 8 and 9, is another particularly interesting case. This culvert has had water backed up six feet above its crown at the inlet and has flowed



PLAN



PROFILE

The cross-hatched zone represents gully scour that has occurred.

FIGURE 17. SCHEMATIC PLAN-PROFILE SKETCH OF PROJECT CULVERT NO. 1

almost full at the outlet. It was mentioned earlier that this culvert had a grouted riprap outlet apron that was completely demolished. It was after the loss of the outlet apron that the vertical cutoff wall, visible in Figure 8, was constructed. Only the top six feet of the ten-foot high cutoff wall are visible in the Figure. After construction of the cutoff wall, large rocks were dumped at the culvert outlet, right up against the cutoff wall. Subsequent high water moved the rocks about 50 feet downstream, to the position shown in Figures 8 and 9, where they formed a "dam" across the outlet channel. The large scour basin, which apparently developed as a result of this accidental riprap dam, now threatens to destroy the cutoff wall and the grouted riprap slope-facing by outflanking it and cutting behind it from each end. It appears that the stream could by-pass the riprap dam by cutting a new channel on either side. However, when the culvert was last inspected in June of 1967, the riprap dam was still intact and no significant changes had taken place since 1963 when the pictures of Figures 8 and 9 were taken. One factor which may account for the relatively long life of the riprap dam is that the outlet channel had previously scoured its way down into a moderately erosion-resistant sandstone stratum upon which the riprap dam rests.

Early plans to analyze the scour problems at the project culverts on a systematic and comprehensive basis which would have correlated scour with discharge, velocity, soil type, slope, etc., ended in frustration because the historic peak discharges could not be ascertained or estimated with

any satisfactory degree of accuracy. Neither could a theoretical computed past flood discharge be used with any confidence because of the highly variable and unpredictable nature of storms in some parts of Montana and the fact that most of the project culverts were less than eight years old. Had such a study been attempted, it is unlikely that it could have added much to the findings of Keeley who, in the Oklahoma study (1) cited previously, successfully related channel scour to certain pertinent soil properties and flow parameters.

For each of a large number of Oklahoma culvert watersheds, Keeley calculated a theoretical storm discharge using a set of drainage area-discharge curves which were thought to give discharge rates falling somewhere between a ten-year and a twenty-year recurrence interval. Since most of his culverts were more than fifteen years old, he felt justified in assuming that each of them had experienced a discharge of this magnitude which he then used to calculate a flow velocity. In some cases he estimated Manning's "n" and calculated both the velocity and the depth. In other cases, he used depths from high water marks to help calculate the velocity, but he did not use any of these results unless the corresponding value of Manning's "n" looked reasonable.

Keeley found that the Froude Number of the aforementioned theoretical storm runoff, in a given channel, correlated well with the presence or absence of channel degradation in that channel. The Froude Number, which is the

ratio of the mean flow velocity to the "critical velocity" was calculated as follows:

Froude Number $$F_n = \frac{V}{(g\ A/T)^{1/2}} \qquad (1)$$

in which

V = mean flow velocity (Q/A), (fps)

g = acceleration of gravity, (32.2 fps^2)

A = cross-sectional area of flow, (ft^2)

T = channel width at the water surface, (ft)

Keeley demonstrated that each of several different soil types could be assigned a threshold Froude Number which defined a condition of incipient scour for a channel in that particular soil. Threshold Froude Numbers abstracted from the Oklahoma report are listed below.

Soil Type	Threshold Froude Number
Sand Silt Soils PI $<$ 6	0.34
Silt Clay Soils PI 6-10	0.34
Soft Shales	0.50
Clay Soils PI $>$ 10	0.55
Soft Sandstone	0.60

A given discharge may be expected to degrade a given channel if the Froude Number is larger than the threshold Froude Number, but not if the Froude Number is smaller than the threshold value. The given values may be cautiously regarded as maximum permissible Froude Numbers if scour is to be avoided in channels in the given soils. They should be of some use outside of Oklahoma as well as in Oklahoma, especially the three for the fine grained soil types classified by plasticity index, or PI.

Keeley's Froude Number approach may be used to explain the existence of localized scour holes at culvert outlets. For example, assume that the calculated Froude Number is 0.2 for a given flow in a proposed clay channel some distance downstream from the outlet, but that it is 1.0 right at the outlet. The channel Froute Number of 0.2 indicates that the downstream channel will be stable, but the high Froude Number right at the outlet indicates that scour will occur at that location. The expected result would therefore be a localized scour basin at the outlet, but no channel degradation downstream.

Keeley's Oklahoma report contains several illustrative examples in which the Froude Number is used to solve practical scour problems. In addition to indicating whether a channel is stable or unstable for a given flow, it is sometimes possible to estimate the ultimate depth to which scour will occur. For instance, if a given recurring flow in an existing or proposed outlet channel in sandy silt has a Froude Number of 0.7, it may then

be assumed that channel degradation will occur. The eventual equilibrium slope, for which the Froude Number will be near 0.34 for sandy silt, may then be roughly estimated by successive trials using assumed final channel cross-sections. This estimated equilibrium slope may then be projected upstream from a known downstream control point if there is one. A downstream control point might be an erosion-resistant rock outcropping, the inlet of an existing culvert downstream, or the stream mouth if it empties into a river a short distance from the culvert. In some cases the control is an erosion-resistant stratum underlying the more easily erodible material.

As an alternate to the Froude Number approach, and using the same basic data, Keeley also developed equations for maximum permissible velocity as a function of normal depth. For each soil type the equation has the same basic form, which is:

$$V = Kd^{0.2} \qquad (2)$$

in which

V = the maximum permissible flow velocity if scour is to be prevented, (fps)

d = the normal flow depth, from water surface to bottom of channel, (ft)

K = a constant which has the numerical values given below for the specified soils

$K = 2.5$ for sand silt soils with $PI < 6$
$K = 2.5$ for silt clay soils with PI 6-10
$K = 3.2$ for soft shales
$K = 3.5$ for clay soils with $PI > 10$
$K = 3.8$ for soft sandstone

The normal depth d was used to develop the relationship, instead of the mean depth A/T, because the normal depth is easily obtainable from the open channel hydraulic design charts used by most designers. It therefore permits a designer to check a given design for potential scour, with a minimum amount of effort.

It is pertinent to note that the influence of the depth term is significant. For the case of a fine grained soil of low PI, the equation gives a maximum permissible velocity of 4 fps if the depth is 11 feet, but only 2 fps if the depth is 0.3 feet.

The relationship correlates very well with the Oklahoma field data from which it was derived, and designers outside of Oklahoma should fine it to be of some value. At the very least it can be used as a supplementary check on the conventional maximum permissible velocity tables upon which some channel designers rely. The formula is, of course, an empirical approximation; for the true threshold scour velocity depends upon a number of factors that cannot be adequately represented by a formula based solely on flow depth and a soil plasticity classification.

In summary, before moving on to another topic, it may be stated that the large culvert surveys in Montana did not reveal any evidence to support the use of grouted riprap outlet aprons at large culvert sites. Aprons of this type appear to have a poor service record in Montana.

Finally, in regard to the design of outlet cutoff walls, it is strongly recommended that the ultimate depth of channel degradation at the outlet be rationally calculated, if possible, and that this depth be added to the cutoff wall depth that would be used at an installation where no channel degradation was anticipated. If three feet is taken as a practical minimum depth for cutoff walls, then an eight foot deep cutoff wall should be used at a site where a five foot depth of channel degradation is anticipated.

Designers should try to avoid designs that will result in outlet channel degradation. In cases where this is not feasible, the principles presented earlier in this section may be used to help predict the depth of channel degradation.

CULVERT INLET SCOUR AND INSTABILITY

The large culvert inspections in Montana did not reveal a large amount of damage resulting from inlet scour. Most of the damage that was observed occurred at culverts that had no inlet protection whatsoever; and some of the culverts that lacked inlet protection had experienced very high water without any significant inlet scour damage developing in spite of the fact that the fill soil was highly erodible.

Figure 18 shows the unprotected inlet of project culvert No. 48 shortly after a 1963 flash flood that piled up water to a depth of 15 feet above the inlet crown. Damage to the steep sandy silt embankment at the inlet appears

FIGURE 18. INLET OF CULVERT NO. 48 AFTER A FLASH FLOOD IN 1963

to be more a matter of sluffing than scouring. This 84 inch diameter culvert is constructed of 10-gage plates.

Shallow inlet undermining, of less than one foot depth, is not uncommon, and fill erosion by inlet eddy currents will sometimes occur unless some protection is provided. At double-pipe installations, an erodible embankment is quite susceptible to scour at the inlet between the pipes. An unbeveled inlet provides some protection to the embankment by moving high speed entrance currents back away from the embankment a short distance.

A shallow cutoff wall and/or moderate riprap protection appears sufficient to prevent serious scour damage at most large culvert entrances.

Cutoff walls or headwalls at culvert inlets are also desirable because they provide structural support to the end of the pipe. The beveled inlet end of a large culvert constructed of thin plates is structurally weak; and the unsupported edge may collapse inward during a flood if the depth of water builds up enough to exert the necessary pressure. The water pressure on the outside of the inlet will always be greater than on the inside, and the pressure difference increases as the depth of water increases. The unprotected inlet of culvert No. 48, shown in Figure 18, had sufficient strength to resist this type of failure, largely by virtue of its relatively small diameter of only seven feet.

A 15 foot diameter culvert, of 8-gage plates, located on Muskrat Creek about two miles east of culvert No. 48 did experience an inlet

collapse during a flash flood in August of 1963. Figures 19 through 22 show the collapsed inlet of the Muskrat Creek culvert. Several inlet failures of this type have occurred in Montana during the past decade and they have prompted the Montana Highway Department to require headwalls on all new installations of similar dimensions.

The headwater depth required to produce an inlet collapse of a culvert of given diameter, gage, and bevel angle, is unknown and constitutes a challenging subject for future research.

Another type of inlet instability results from buoyancy when a submerged culvert flows only partly full. A length of culvert which extends upstream some distance beyond an embankment may be bent up into the air if it has insufficient strength as a cantilever beam to resist the upward buoyant force. A headwall also reinforces a culvert inlet against this type of failure.

Another type of culvert-end instability, which is limited to jointed concrete culverts, is characterized by one or more end sections falling off. A slight amount of undermining, at either the inlet or the outlet, may bring about this condition. Two experimental culverts, which utilized tie-bolts and cutoff walls to eliminate this problem, were included among the project culverts, upon the recommendation of Highway Department engineers, and will be discussed in the next section.

FIGURE 19. COLLAPSED INLET OF THE MUSKRAT CREEK CULVERT

FIGURE 20. THE COLLAPSED INLET OF THE MUSKRAT CREEK CULVERT AS VIEWED FROM ABOVE AND OFF TO ONE SIDE.

FIGURE 21. CLOSE-UP VIEW OF THE TOP PART OF THE COLLAPSED INLET OF THE MUSKRAT CREEK CULVERT.

FIGURE 22. THE COLLAPSED INLET OF THE MUSKRAT CREEK CULVERT, AS VIEWED FROM INSIDE THE CULVERT. Notice the greatly reduced inlet waterway area.

REINFORCED CONCRETE PROJECT CULVERTS

The two reinforced concrere pipe culverts with the tie-bolted end sections (selected as project culverts Nos. 3 and 4) were installed in the fall of 1961 on Route 359 in Madison County, on Little Antelope Creek and Antelope Creek.

Each culvert is nine feet in diameter, has a concrete cutoff wall at each end, and the three pipe sections closest to each end are bolted together by pairs of tie-bolts situated about three feet below the crown on the outside of the pipes.

Figures 23 and 24 show the inlet end of project culvert No. 3. Notice in particular, the tie-bolt across the joint near the center of Figure 24. The inlet and outlet of culvert No. 4 are shown in Figures 25 and 26 respectively. One of the tie-bolts at the outlet is visible in Figure 26. The pictures were taken in 1963, but the appearance of each culvert remains essentially the same in 1967.

The tie-bolts and cutoff walls appear to be doing their intended jobs perfectly. Both culverts are in excellent condition. There has been no indication of undermining or separation of the end sections in spite of the fact that the soil is highly erodible and each culvert has carried a very heavy flow of water, with the headwater pool above the elevation of the top of the pipe. Fresh evidence of this flood was visible in the summer of 1963 when the

FIGURE 23. INLET OF PROJECT CULVERT NO. 3

FIGURE 24. RIGHT SIDE OF INLET, CULVERT NO. 3

FIGURE 25. INLET OF PROJECT CULVERT NO. 4

FIGURE 26. OUTLET OF PROJECT CULVERT NO. 4

pictures were taken, so it is assumed that it occurred in the spring of 1963. In Figure 25 the high water line is visible on the embankment slope, about three feet above the top of culvert No. 4. There was a similar high water mark just barely above the top of the inlet of culvert No. 3.

One other reinforced concrete pipe culvert (project culvert No. 53) was included among the project culverts upon the recommendations of engineers in the State Highway Department. This one was a 6-foot diameter pipe that had experienced a structural failure shortly after construction in 1956, but had continued to adequately serve its purpose under a 34-foot high embankment about six miles south of Havre, Montana.

The pipe cracked severly and deformed until its vertical diameter was only 5-1/2 feet in the center region. Figure 27 is a picture of this culvert taken from the outlet end. Figure 28 is a close-up view of one of the severe cracks in the floor region. Eighteen of the 23 pipe sections are cracked. The appearance of the culvert has not changed since 1963, and measurements of its horizontal and vertical diameter have shown no change.

To lengthen the useful life of this culvert, it is recommended that the large open cracks, like the one shown in Figure 28, be trimmed up with a chisel, cleaned and grouted.

SEDIMENT AND ABRASION

The large culvert inspections and surveys did not reveal any serious

FIGURE 27. CULVERT NO. 53, AS VIEWED FROM THE OUTLET

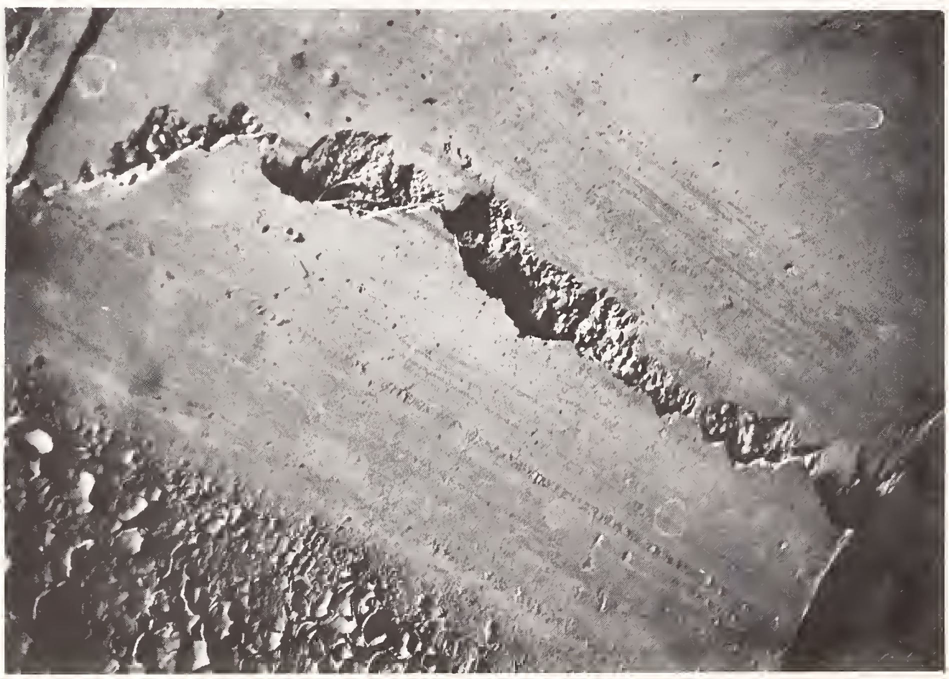


FIGURE 28. CRACK ON FLOOR OF CULVERT NO. 53

FIGURE 29. FIVE FEET OF SEDIMENT IN CULVERT NO. 7

FIGURE 30. CULVERT NO. 28 WITH A FIVE FOOT DEPTH OF SEDIMENT
This installation blends in gracefully with the terrain.

sediment problems at large culvert installations in Montana. Seven of the 55 project culverts[1] contained sediment of two-foot depth or greater, but there was no indication that the sediment was detrimental to the installations.

Figure 29 shows project culvert No. 7, at the Nissler Overpass near Butte, which had a five-foot depth of sediment when the picture was taken. This culvert was intentionally installed approximately four feet low in the highly mobile sand-gravel bed material. Most if not all of the sediment undoubtedly scours out during floods when more culvert capacity is needed; and the culvert does a much better job where it is than if it had been installed higher. As it is, very serious flooding of an adjacent railroad track would occur if the headwater pool ever got as high as the top of the culvert.

The railroad track almost washed out in December of 1955 when an unusual flood, with an estimated discharge of 1400 cfs, occurred. The water surface at the inlet was 1'1/2 feet below the top of the culvert at that time, and the culvert was estimated to be carrying less than half of the total discharge--the rest was running under the overpass, alongside the railroad tracks, and seriously scouring the railroad embankment. The low-flow sediment deposit was not to blame for the flood. The culvert was merely too small to handle so large a flow with the required low headwater elevation.

[1]Project culverts 7, 12, 14, 26, 28, 36, 43

After the flood, a pipe-arch relief culvert (12'-8" x 8'-1") was installed adjacent to the railroad embankment to carry similar overflows that might occur in the future. The relief culvert has experienced a structural failure which will be discussed in a later section of this report.

Another project culvert, in a stream having a mobile sand-gravel bed, is project culvert No. 28, south of Miles City. Under no-flow conditions this twin 15-foot diameter installation contains about five feet of sediment which is evident in Figure 30. The limited amount of available headroom and the mobile bed material both suggest that these pipes were purposely installed low. According to a widely quoted "rule of thumb", each one-foot rise in water level is accompanied by a one-foot increase in the depth of scour, for streams with mobile sediment beds. On this basis, one would expect all of the sediment to be scoured out of the culverts of Figures 29 and 30 before they ever came close to flowing full. This argument gains additional support from the fact that the velocity of flow inside the culverts will be higher than the normal stream velocity as a result of the channel-constricting effects of the culverts.

Figures 31 and 32 show project culvert No. 12, a twin pipe-arch installation, as it appeared in the summer of 1963, with a two-foot depth of boulder-size sediment in one barrel and about half that amount in the other. The reason for the sediment deposit in this case is apparent in Figure 32. Large rocks were dumped in the channel, about 25 yards downstream from

FIGURE 31. SEDIMENT IN CULVERT NO. 12
The right barrel of this pipe-arch installation contains a 2-foot depth of sediment.

FIGURE 32. A RIPRAP DAM DOWNSTREAM FROM CULVERT NO. 12

the culvert, to protect a railroad trestle against scour. These rocks formed a dam, about two feet high, which resulted in a corresponding rise of the streambed upstream from the dam. This is a highly predictable case of channel aggradation.

An inspection of the same installation in the summer of 1964 revealed that the left end (facing downstream) of the riprap dam had washed out and the channel was scoured out on that side down to its apparent pre-dam level; also, the culvert barrel on that side had been swept clean of sediment. The other barrel still had a two-foot depth of sediment. When the installation was last inspected in July of 1967, the riprap dam had been repaired and channel aggradation had once again occurred to the extent that the left barrel now contained almost as much sediment as the right barrel.

Both functionally and aesthetically, a foot or two of granular sediment in a large culvert, under low-flow conditions, is advantageous. It makes the culvert blend in better with the landscape and the streambed maintains a natural appearance through the culvert. It also protects the culvert floor from abrasion except during periods of unusually heavy flow when the sediment is scoured out.

An obvious method to encourage the deposition of a moderate amount of sediment in a culvert is to install it low. At numerous sites it appears that it would be advantageous to install large culverts with the invert below the natural low-flow streambed by an amount equal to approximately one-fifth of the culvert diameter.

The fear that a culvert may clog with sediment seems to be a major deterrent to the practice of installing culverts low, and for small culverts the fear is undoubtedly justified. However, for culverts of seven-foot diameter or larger, the danger of clogging by sediment appears to be slight. The large culvert inspections in Montana did not reveal a single site where there appeared to be any danger of a large culvert becoming clogged with sediment.

Special cases do arise, of course, when the equilibrium of a stream is drastically upset in a way that causes it to aggrade its channel sufficiently to bury culverts, highway embankments, and other things that happen to be in the way. For example, extensive soil erosion resulting from logging operations in a highly erodible watershed might bring on this condition by supplying a vast quantity of sediment previously not available.

Sediment could bury a culvert inlet during a single flood if the inlet first became plugged by floating debris. The use of debris racks, and the removal of debris as a routine maintenance measure, greatly reduces the liklihood of this type of functional failure. In the absence of debris, the high flow velocity at the inlet, during floods, will keep that region free from sediment deposition even though sediment may be building up at the same time on the bottom of the inlet pool where the incoming water is drastically slowed down before it reaches the culvert. At some locations a large pond will form upstream from a culvert during high water and large-size sediment will be

deposited several hundred feet upstream from the culvert, while gravel and sand are being deposited closer to the culvert.

Project culvert No. 51 which carries the South Fork of the Dearborn River under Route 434, northwest of Wolf Creek, Montana, provided a good example of the latter phenomenon during the flood of June 1964. During the flood, the twin ten-foot diameter pipes flowed approximately three-fourths full at the inlet and a relatively shallow inlet pool, of great horizontal extent, formed. Figure 33 is a picture of the upstream channel taken after the flood had subsided.

A large sandbar is visible in the center of the picture. In the foreground, closer to the inlet, the water velocity was apparently large enough to prevent the deposition of sand, and the sediment there is somewhat larger in size which is also the case just upstream from the sandbar. In the background, beyond the trees, is a swampy area, presumably formed by the damming action of the sandbar. Within the swampy area there are deposits of large boulders up to approximately one foot in diameter.

In general, as an inlet pool subsides, following a flood, the stream will confine itself to a narrow channel as it appraches the culvert inlet, scouring through sediment bars deposited earlier, if necessary.

The net scour and sedimentation pattern produced by a particular flood at a given site is profoundly influenced by a number of flood characteristics, of which the peak flow rate and the duration of near-peak flow are

FIGURE 33. THE CHANNEL UPSTREAM FROM CULVERT NO. 51, AFTER THE 1964 FLOOD

only two. Another factor which appears to have an important influence is the rate at which the flood subsides, or the duration of "some range of intermediate flow" as the flood subsides. This factor seems to be important for a stream that transports no sediment under normal flow conditions, but does transport sediment during intermediate flood flow conditions.

For example, the maximum dimensions attained by a scour hole at a culvert outlet may depend upon the peak discharge rate and the duration of near peak flow; however, as the flood subsides, the hole may partially or completely fill with sediment. Whether or not it will depends, apparently, upon the time required for the diminishing flood to "pass through" an intermediate sediment deposition stage. A flash flood, that recedes very rapidly, may leave a large gaping scour hole that might have been filled with sediment if the flood had receded more slowly. The same final condition could result from a large abrupt flood that leaves a deep scour hole which eventually fills up with sediment from one or more subsequent smaller floods.

Heavy sedimentation, of previously very prominent outlet scour holes, was observed at project culverts Nos. 4 and 13 in July of 1967, following a moderately heavy spring runoff of unusually long duration. The runoff receded very slowly as a result of slow melting of heavy mountain snowpacks. At culvert No. 13, a large gravel bar now hides all evidence that a broad and deep scour hole once existed at the site. At culvert No. 4, the external boundaries of the large outlet pool (which is visible in Figure 26) are still

prominent, but sediment has reduced the pool depth to one foot or less, in contrast to its previous depth of approximately four feet.

In regard to the abrasive action of sediment, sand size sediment has been known to wear out metal irrigation pipes by abrasion in less than one irrigation season; however, not a single case of serious abrasion was found during the large culvert inspections and surveys in Montana. It is theorized that most natural Montana streams, of a size on which culverts are used, do not transport abrasive sediment during a sufficient percentage of the time to make abrasion a generally serious problem in the state. Boulder-size sediment will, however, frequently knock the galvanizing off the invert region of culverts. This condition was observed in ten of the 55 project culverts.[1] The problem is not as serious as one might think because the bare areas still receive cathodic protection against corrosion from the adjacent areas that still have their zinc coating.

CORROSION

The total amount of corrosion damage observed during the large culvert inspections in Montana was surprisingly small. This was due in part to the fact that most of the large culverts observed were less than twenty years old, and a substantial proportion of these were less than ten years old.

[1] Project culverts Nos. 10, 11, 12, 13, 25, 31, 40, 41, 42, 51

Without doubt, much more corrosion, and also abrasion, would have been observed if a substantial number of culverts had been older--say thirty years of age. Furthermore, it is virtually impossible to detect some cases of serious corrosion, on the buried outside surface of culverts, until it has reached an advanced stage.

As it turned out, only six large culverts, out of the 400 or more inspected, exhibited significant corrosion, and all six of these were included among the 55 project culverts.[1]

A geologist's pick was used during the culvert inspections, with the hope that the penetration or rebound of the pick striking the plate could be used to estimate the remaining thickness of metal. In California studies, Beaton and Stratfull (3) reported good success with this method on relatively small, thin, metal culverts. However, it did not prove to be of great value on the large structural plate culverts in Montana. For one thing, there just were not enough badly corroded culverts available to practice on to detect differences in the reaction of the pick to different thicknesses of metal.

A reliable, but slow and inconvenient method to determine metal loss, is to drill holes through the walls and observe metal thickness directly. Punching holes is faster than drilling, unless a good power drill is available.

Six to ten blows from a three-pound hammer, on a 3/16" punch, will penetrate a 10-gage plate. Persons punching holes in culverts should wear

[1] Project culverts Nos. 9, 10, 11, 12, 25, 45

goggles to protect their eyes from flying bits of steel that occasionally spall away from the top of the punch; and the punch should be tightly clamped and held in a pair of good vise-grip pliers to minimize the danger of smashing fingers or hands.

For either a drilled or a punched hole, the burr at the bottom of the hole should be taken into account when measuring the metal thickness.

Although no reliable estimate of metal thickness could be made with the geologist's pick, the pick is still considered to be a useful tool for the inspection of large culverts, because it will reveal if corrosion is far enough advanced to permit the pick to penetrate the wall at any spot where it is struck. Some cases of very advanced corrosion could be overlooked if a pick were not used; however, its diligent use does not guarantee that all serious cases of corrosion will be found because corrosion is sometimes so highly localized that a plate may be perforated by corrosion in many places without having lost a large amount of metal, overall. A sharp blow with a pick, within a fraction of an inch of one of these local perforations, will, as often as not, encounter firm metal-to-metal resistance that gives no hint of the nearby perforation.

The zinc coating on the inside of a culvert could be entirely intact at a time when localized corrosion was on the verge of perforating the wall in several places. A highly ambitious pick-swinger would conclude that the culvert was perfectly sound unless he were lucky enough to accidentally hit

one of the points of incipient perforation. Project culvert No. 9 was practically in this condition when it was first inspected in the summer of 1963, six years after its installation. The zinc coating on the inside walls looked intact, the walls solidly resisted blows from the pick, and two inspectors were ready to report no indication of corrosion until one of them decided to wipe his finger across an innocent looking little heap of yellowish white powder that looked very much like dried and weathered bird droppings. Underneath this little heap of powder was a very small rusty spot that collapsed when poked with a pencil-point. A diligent search through the entire 166-foot length of the culvert revealed only ten spots where localized corrosion had penetrated the walls, apparently very recently because there were no rusty stains around the spots. One year later a total of 36 perforations were counted and several of these would have been apparent to a casual inspector because water had seeped into the culvert through the perforations, and stained the wall with narrow, brown rusty streaks below the points of perforation. In june of 1967, a rapid count revealed 120 perforations. All of the perforations were below mid-height in the culvert, roughly within the "4 to 5 o'clock" or the "7 to 8 o'clock" zones.

The corrosion caused by a corrosive backfill soil is likely to be most severe in this haunch zone, just above the invert, because the backfill in this zone will be wet most of the time and provide an environment more conducive to corrosion than exists in drier locations. The invert or floor

may "escape" corrosion entirely if it is bedded on a granular material that keeps it out of direct contact with the corrosive backfill.

Project culvert No. 45, which was installed in 1952, dramatically illustrates both the protective effect of granular bedding and the role of moisture in promoting corrosion. This culvert suffers from an advanced case of the same kind of localized corrosion described earlier. It was perforated in dozens of places on the sides, and a few places on the roof, when it was first inspected in the summer of 1963, and its condition has steadily worsened. A perforation count in December of 1966 revealed approximately 830 perforations, with a large majority of them in the bottom half of the culvert, but not a single one in the floor plates, which are bedded on a two-foot thick layer of gravel. The backfill soil, for both this culvert and culvert No. 9, is a highly heterogeneous mixture of plastic clay and rotten shale derived from the Bearpaw shale formation which outcrops over a large area of north-central and north-eastern Montana.

Of the 830 perforations in culvert No. 45, only 170 were counted in the roof plates which comprised the upper forty percent of the culvert's circumference and which have a relatively dry environment. The remaining 660 perforations were in the side plates, which also covered forty percent of the circumference. The remaining twenty percent of the circumference was the floor zone which was bedded on gravel and did not contain any perforations. The total absence of perforations in the floor is attributed to the gravel

bedding which keeps the floor plates out of direct contact with the corrosive clay and shale. The gravel bedding also provides easy paths for seepage water to flush corrosive salts away during periods of heavy flow, which are rather infrequent at this installation. Also, during the long dry spells when there is no flow of water in the culvert, the free-draining gravel bedding undoubtedly provides a drier environment for the floor plates than the poorly draining clay and shale provides for the adjacent side plates where the corrosion is most severe.

The location of the perforations on the plates, in both culverts, 45 and 9, is rather interesting. In the roof and side plates, a very large majority of the perforations are on the ridges of the corrugations, as viewed from inside the culvert. They would therefore be in the corrugation valleys as viewed by an outside observer. One plausible hypothesis, to help explain this, is that water coming in contact with the outside walls of the culvert, anywhere above midheight, will be encouraged by gravity to run from the corrugation ridges into the corrugation valleys. This greater concentration of moisture in the outside valleys would intensify the corrosion reaction there, and thereby account for the greater frequency of perforations in those locations.

California studies (4) have shown that the old, relatively uncontrolled type of hot-dip bituminous coating increased the average service life of culverts carrying corrosive flows by about six years, but that a twenty year

increase in service life could be expected if the source of corrosion was an alkali soil in a desert region. This suggests that bituminous coatings might be of considerable value for metal culverts in corrosive alkali soils in Montana.

A study of bituminous coatings, or other coatings, was beyond the scope of this project. None of the project culverts were coated and only a few coated culverts were encountered during the preliminary large culvert inspections. Most of these were new installations in the vicinity of Butte.

The absence of corrosion on the floors of culverts 45 and 9 suggests that it might be feasible to protect a culvert from corrosive embankment soil by completely surrounding it with non-corrosive granular backfill material. This might not be entirely effective, however, because highly corrosive material could leach out of the embankment soil and be carried to the outside surface of the culvert by percolating water. In the upper part of the culvert, in contrast to the floor region, the corrosive elements would seldom be flushed away by storm seepage flow.

Future experimental research, to determine the extent of the corrosion protection provided by granular backfill, would be worthwhile and should be a matter of more than casual interest; particularly in view of the fact that granular backfill is also highly beneficial for structural reasons and might also be useful, in some cases, to prevent internal soil erosion or piping--a topic which will be covered later in this report.

Granular backfill will not, of course, protect a culvert from a corrosive flow of water. Acid water is the apparent source of the unique floor corrosion that was observed in project culverts 10, 11 and 12, south of Florence, in the Bitterroot Valley. These culverts carry continuous flows from clear mountain streams that originate high in the mountains but also drain agricultural land on the valley floor. At the culvert sites, the clean rocky streambeds and crystal clear waters furnish no hint that a corrosion problem exists, but the floor of each culvert is badly corroded in the region that remains under water when the flow is very small. In this region the plates are covered with a hard, thin, coat of rust out of which protrudes numerous hard, dense, corrosion nodules or tubercles, which are almost hemispherical in shape and typically about one-fourth inch in diameter. Figure 34 is a close-up view showing the corrosion nodules on the floor of culvert No. 10.

The nodules are light brown in color and contrast markedly with the dark reddish-brown background rust. A casual observer might conclude that the floor had a smooth uniform coat of dark rust and mistakenly assume that the nodules were particles of small gravel-size sediment.

The nodules are firmly attached to the plates and a sharp blow is required to break one off. When this is done, the exposed metal is clean and bright, but there is usually a small but deep pit at the center.

FIGURE 34. CORROSION NODULES ON THE FLOOR OF PROJECT CULVERT NO. 10

The nodules also exist on the under-side of the floor--at least at the outlet end of culvert No. 10 where they could be felt with the fingers on the bottom side of the floor plates.

In culverts 10 and 11, a few of the pits were as much as 0.07 inches deep, which is approximately half the thickness of the plates. In culvert No. 12, there were fewer nodules and the pits beneath them were not as deep as in the other two cases, but in some places the uniform coat of dark rust on the floor of the left barrel appeared to be quite thick. In the summer of 1964, a hole was drilled at one of the rustiest spots, and it revealed that about a ten percent loss of metal had occurred at that spot.

Culverts 10, 11 and 12 were installed in 1956. The corrosion now appears to be proceeding at a slow rate, because in 1967 it was not discernably worse than it was in 1963. Water samples taken at the three sites on July 15, 1967, had pH values in the range of 6.7 to 6.9, which is only very slightly acidic. However, when the water samples were taken, the stream flow rates were still considerably higher than the minimum flow rates that usually prevail in the autumn. It is theorized that the water in all three streams reaches a condition of maximum acidity at the time of minimum flow but this has not been verified.

Although superficial rust was visible in many culverts, the only other project culvert that appeared to have a serious corrosion problem was culvert No. 25. In places the invert appeared to be heavily rusted and it had a rough

pitted appearance, with the deeper pits being about 0.04 inches deep. It also appeared that some metal might have been lost by abrasion near the top of the floor corrugations, on the upstream side. However, drilled holes revealed that the metal loss from abrasion and rust combined was only about 0.02 inches, except at the pits. At the deepest pit observed, the metal thickness was still 0.16 inches. This was in 5-gage plate which had an original thickness of about 0.21 inches.

White alkali deposits were present in several culverts inspected in eastern Montana. Usually this was on the floor, or at seams where alkali-laden water from the surrounding soil had seeped in and left a white deposit of frosty appearance. The very badly corroded project culvert No. 45, discussed earlier, had white frosty alkali deposits on the floor and at numerous seams. Culvert No. 9, similarly corroded, had alkali deposits on the floor. The other culverts, observed to have white alkali deposits, did not show any evidence of serious corrosion. The alkali deposits are, however, a good indication that the surrounding soil has low electrical resistivity, which is conducive to rapid corrosion. When an inspector sees alkali deposits in a culvert, he should suspect that there may be corrosion occurring on the outside of the culvert, even though none is visible on the inside.

Beaton and Stratfull (4) of the California Division of Highways, have developed a relatively simple method of estimating the service life of corrugated metal culverts. It requires measurements of the pH and the electrical

resistivity of the embankment and foundation soils and the stream water. The pH and resistivity values are entered in a chart from which is read the estimated number of years to perforation for a 16-gage metal culvert. The time of perforation is assumed to be directly proportional to plate thickness. For example, a 10-gage plate, which is 2.3 times as thick as a 16-gage plates, is assumed to have a life 2.3 times as long as that of a 16-gage plate.

In retrospect, it is clear that a detailed pH and resistivity analysis at certain large culvert sites in Montana, especially at project culverts 9, 10, 11, 12, 25 and 45, would be a valuable study to undertake in the future, to see how well the California method would predict the observed corrosion distress of those culverts.

Although the corrosion history of culverts in a given geographical area is of great value for predicting corrosion problems at future culvert installations in the same area, it is certainly not a satisfactory alternative to a quick and simple test that could be applied to assess the corrosion potential at any proposed culvert site, at the time of the test. Soil and/or water conditions can differ greatly within a very short distance, and they can also change dramatically with time.

A change in land or water usage within a watershed could create a severe corrosion potential where none had existed before. Long-term corrosion history would be a very poor indicator of future corrosion in such an area. A rapid site test has the advantage of indicating the present corrosion potential at a site, regardless of what it may have been in the past.

It is recommended that the Montana Highway Department actively make use of the latest version (5) of the California field test that was first developed by Beaton and Stratfull (4), to identify "corrosion-prone" culvert sites. The method is based on studies conducted at more than 7000 culvert sites and there is no reason to expect that the pH-resistivity-corrosion relationship observed in California would not also be reasonably applicable in Montana.

CAMBER AND DEFLECTIONS

For each of the 55 project culverts, the construction field notes were studied to determine, if possible, the amount of camber introduced at the time of construction. The results are tabulated in the condensed summary of survey findings in Appendix B, Table B2, which also gives the camber observed in the field during the 1963 culvert surveys. No significant problems attributable to the use of too much or too little camber were encountered, and it is concluded that large culvert camber is not a pressing problem in Montana.

Inside height and/or width measurements were also taken, when feasible, in each of the project culverts, near each end and near mid-length, and these were compared with the nominal standard dimensions which were the original dimensions, presumably. Table B3 in Appendix B gives the apparent original dimensions, the observed dimensions, and the observed difference, to the nearest percent, which is reported as the apparent percent change. In a few cases, the observed differences appear to be questionable

and it is assumed that the true original dimensions sometimes differed significantly from the nominal standard dimensions. This points up the necessity for taking a set of initial reference measurements, from permanently marked reference points, and then taking later measurements from the same marked reference points, to get consistently reliable determinations of culvert deflection.

The reader will notice that the camber and deflection data in Appendix B are not complete. Camber and height measurements were usually not taken in culverts which had a significant amount of sediment on the floor, and no measurements were taken in culverts carrying a heavy flow of water at the time of the surveys.

Recognizing the necessarily approximate nature of the "observed" apparent deflections, it is still considered significant that approximately one-third of the project culverts indicated an apparent height and/or width change of five percent or larger. This is not in itself alarming, because a round metal culvert can usually tolerate a deflection in excess of five percent without experiencing any damage.

Some of the cases of observed large deflections were associated with definite culvert distress of some sort. For example; culvert No. 53, with a vertical deflection of eight percent, is the badly cracked reinforced concrete pipe culvert discussed earlier. Culverts Nos. 1, 7A, 29, 36, 37 and 44 all exhibited severe structural distress which included cracked plates at certain

bolted seams. High bending moments, resulting from inadequate lateral support or excessive loads, apparently caused the cracking (this matter will be covered in detail in the special studies section of this report).

Most of the culverts with cracked plates did exhibit large deflections. However, culvert No. 29 is a cracked pipe-arch that showed a height change of only four percent and a width change of only one percent. Pipe-arches have rather flat floors that effectively prevent large changes in width or span. Culverts No. 1 and 36 are badly distorted and cracked pipe-arches that showed width increases of only three percent and four percent respectively. Culvert No. 37 is also a badly cracked pipe-arch and it shows a height change of ten percent, but a width change of only four percent.

Culvert height and width measurements are relatively easy to make and they can reveal important clues to a culvert's structural behavior. There would appear to be much merit in maintaining permanent files of periodic height and/or width measurements of large culverts. Specific recommendations on this matter will be presented later in this report.

MISCELLANEOUS OBSERVATIONS

Certain miscellaneous conditions, deemed to be of sufficient importance to warrant some attention in this report, were observed with sufficient frequency to make firm impressions upon the researchers.

Bolt and Nut Orientation

Early in the course of the project, it became apparent that the bolt heads and/or washers of special shape, which were designed to intimately fit the contours of the corrugation ridges or valleys were not consistently installed with the proper orientation to take advantage of the intimate fit that the special shapes made possible.

Different culvert bolt manufacturers have used different bolt head configurations and have changed them from time to time, but one thing that the various specially shaped bolt heads, or washers, have in common is that they conform properly to the plate contours only when individually orientated to insure the proper fit. Random or uncontrolled orientation will generally result in a poorer fit than if ordinary symmetrical shapes had been used.

Numerous improperly orientated bolts were observed in 14 of the project culverts. Of all the inspected culverts that had bolts of the preferred orientation type, it is estimated that half of them exhibited improper bolt orientation to a significant extent. A similar washer condition was also observed in the culverts where washers were used under the nuts. Furthermore, it was not uncommon to find washers that had been installed upside down, or washers that had been fractured by over-tightening of the nuts.

It is concluded, from the numerous observed cases of poor orientation, that culvert construction crews have frequently not been required to

install culvert seam bolts with the preferred orientation that the bolt designers had in mind. Perhaps this has been a factor contributing to the current trend toward the abandonment of preferred orientation bolts in favor of bolts and nuts having symmetrical "spherical" bearing surfaces that bear against the edges of the hole only, and wedge down into the hole slightly when the nuts are tightened.

Low Point on Vertical Curves

Another observed condition which impressed project personnel was the greater severity of embankment side-slope erosion near the low points of sag vertical curves where a concentration of surface runoff occurs.

Rills several inches in depth are very common on embankment side-slopes in Montana (side-slope erosion of this degree or worse was observed in the vicinity of at least 27 of the project culverts), but near the sag points the rills sometimes become gullies a foot or more deep. If a culvert is located directly beneath the lowest point on the curve, the erosion gullies may undermine the riprap or the headwalls, and contribute significantly to the inlet and outlet problems. This situation should be recognized and eliminated at the grade-line design stage by keeping the low points of sag vertical curves reasonably far away from culvert sites.

An even more compelling justification for the observance of this design principle is that it protects culverts from washout by unusually heavy floods

that sometimes overtop embankments and wash them completely out in the vicinity of the "dip".

The foregoing remarks are offered merely as pertinent reconfirmation of a design principle that has been widely recognized and observed by many designers for a long time. It may be a relatively minor consideration in the over-all highway design picture, but it should not be dismissed as trivial.

The flood which buckled the inlet of the Muskrat Creek culvert, discussed earlier, also overflowed the embankment and caused considerable erosion damage at a location which was, fortunately, several hundred feet from the culvert.

A flash flood in the spring of 1964 almost overflowed the embankment right at the station of project culvert No. 45, which is situated directly beneath the dip. As it was, a deep gully was cut in the side slope, directly above the culvert outlet, by runoff from the pavement.

Random Riprap Gradation

During the large culvert inspections, the research workers observed numerous installations where random riprap of essentially one size was used for inlet or outlet protection. The lack of gradation produced numerous large holes between rocks, through which erosion of the embankment soil and undermining of the riprap could occur or had occurred. Project culverts 3, 4, 13 and 38, are four specific examples where it is believed that graded riprap

would have been more effective than the large single-size riprap observed at these sites.

The superiority of graded riprap over single-size riprap is a well-documented fact which is reviewed in a BPR leaflet entitled "USE OF DUMPED STONE FOR BANK PROTECTION" (6), and in BPR Hydraulic Engineering Circular No. 6(7). Each of these papers contains a sizeable list of authoritative references on the subject.

The current Standard Specifications for Road and Bridge Construction (8), adopted by the Montana Highway Commission as of March 1, 1966, are believed to be undesirably permissive in regard to riprap gradation. The size specifications for random riprap, as found on page 255 of that document, are quoted below in full:

> TYPE A. At least eighty percent by weight of the stone or fragments shall have a volume of not less than one cubic foot or a weight of not less than one-hundred-fifty pounds.
>
> TYPE B. Not less than forty percent of the total column shall be composed of stones having a volume of not less than four cubic feet with a minimum dimension of twelve inches and not more than twenty percent of the total volume may be composed of stones having a volume of less than one cubic foot with a minimum dimension of four inches.

From the above, it is apparent that a single-size material of one cubic foot or larger size would meet the size requirements for type A riprap; and a single-size material of four cubic feet or larger size would meet the requirements for type B riprap.

It is recommended that the Montana random riprap specifications be reviewed and revised to require a gradation in size, from a specified median size down to a minimum size of two to four inches, mean diameter. Ideally, riprap should function as a filter with pores sufficiently small to prevent migration of the material upon which the riprap is placed. This matter will be taken up in detail in the special studies section of this report, which follows.

CHAPTER IV

SPECIAL STUDIES

Two of the most serious types of distress observed at large culvert installations in Montana were piping, or internal erosion, of embankment soil under or alongside culverts, and cracking of the plates along bolted seams in certain structural plate culverts. These two problems, and the closely related problem of backfill condition determination, were singled out for special study and the results are presented in this section of the report.

BACKFILL CONDITION STUDIES

From the start of the Large Culvert Research Project, it was apparent that there was a need for a rapid and reliable means of determining the condition of the backfill adjacent to large culverts. Striking the inside walls with a hammer, and qualitatively judging the backfill condition from the sound and feel of the blows, was considered to be too crude and unreliable. Professor Martin E. Moss, of the Department of Civil Engineers and Engineering Mechanics at Montana State University, suggested the use of the Schmidt Hammer; and it proved to be a useful tool for estimating backfill condition.

Schmidt Hammer and Punch-Hole Surveys

The Schmidt Hammer is an instrument that was developed to judge the strength and uniformity of hardened concrete from hammer rebound readings. It has a steel plunger at one end which is positioned on the surface to be

tested. The body of the hammer is then pushed down on the plunger until the movement triggers a spring-loaded weight inside which strikes the plunger and rebounds. In rebounding, the weight pushes a slider along a graduated scale on the side of the instrument; and the scale reading at the final position of the slider furnishes a numerical measure of the rebound which is recorded as the Schmidt Hammer reading.

In structural plate culverts, Schmidt Hammer readings are taken with the plunger carefully positioned, perpendicular to the plate, in the inside valleys of the corrugations. A rough zinc coating would cause initial readings to be low and erratic, but if repeated readings were taken at the same spot, the readings would increase as the hammer beat the surface down to a smooth condition that provided better contact with the hammer plunger.

In concrete culverts, the Schmidt Hammer could provide no clues to backfill condition because the walls were too rigid and massive, but it was fairly sensitive to variations in the condition of the backfill in contact with structural plate culverts.

The Schmidt Hammer was first used on the project in 1963, in project culvert No. 6, near Cardwell, where a known piping hole existed. With the readings from this 10-gage culvert, a tentative scale was established to estimate the firmness of the fill behind the plates. Readings below 28 were considered to indicate emptiness; between 28 and 34, soft or loose fill; and

34 and higher, firm fill. A Schmidt Hammer survey of most of the project culverts was completed in 1963.

During the summer of 1964, in an attempt to establish a more reliable scale for indicating the backfill condition, holes were punched at points of known Schmidt Hammer reading, with a steel punch and a three-pound hammer, in 28 of the 55 project culverts. Through these holes, the backfill was examined with a flashlight and an eighth-inch probing wire. After the examination, the holes were sealed with silicone rubber construction sealant.

The sequence of operations was as follows: first, a Schmidt Hammer reading was taken at the selected point; second, a hole was punched; third, the fill was observed with a flashlight and probed with the wire. Notes were recorded, listing the Schmidt Hammer reading and the fill condition. The fill condition was reported as firm if the fill resisted penetration by the probing wire or permitted only slight penetration under heavy pressure. It was recorded as soft or loose if the wire could be pushed in several inches or more with slight to moderate pressure.

Table I gives a summary of the results. Other variables, in addition to the fill condition, that affected the readings, were: the plate thickness, the plate curvature, and, of somewhat secondary importance, the orientation of the hammer. A more complete tabulation of the results is given in Appendix C.

TABLE 1 RANGES OF SCHMIDT HAMMER READINGS FOR DIFFERENT VARIABLES.

At least 80 percent of the readings taken are included in the ranges shown

CULVERT TYPE AND REGION OF READINGS		METAL THICKNESS AND FILL CONDITION								
		10 GAGE			8 GAGE			3 GAGE		
		EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
CIRCULAR	BOTTOM HALF	25±2	29±4	38±4	---	---	---	---	---	---
PIPE - ARCH	WALL	31±2	35±3	40±2	---	40±3	42±1	41±1	41±2	46±2
	18" RADIUS CORNER	30±4	39±3	44±2	40±1	44±3	50±2	41±2	44±2	50±2
	FLOOR	24±3	30±3	37±3	33±3	34±4	40 One Reading	40±2	---	46±2

From the Schmidt Hammer and punch-hole survey results, it is concluded that the Schmidt Hammer does have value as a culvert inspection tool. However, it is not sufficiently sensitive to always clearly distinguish between one fill condition and another.

It was theorized that a greater sensitivity and a larger range in readings might be obtained if a different shape of plunger head was used on the Schmidt Hammer; however, this proved to be false. To investigate the effect of different shapes, hemispherical and conical plunger heads were made for the Schmidt Hammer and given trial usage in the summer of 1965. Both shapes provided a very small contact area between plunger and culvert and, because of this, a significant amount of plastic flow of the culvert metal occurred under the blow of the hammer. This dampened the rebound so that the readings were much smaller, and less sensitive to backfill condition, than with the standard head. The standard plunger head has slightly convex curvature which almost matches the curvature of the inside valleys of corrugated structural plates and provides as good a bearing surface between the plunger and the plates as it seems practicable to try to achieve.

Nuclear Moisture-Density Meters

Pilot experiments were also conducted in two culverts, with nuclear moisture-density meters, to see if the meters could detect the presence of empty space behind culvert walls. On July 20, 1966, a Nuclear-Chicago surface moisture-density meter was used in project culvert No. 6 near

Cardwell, Montana. On August 11, 1966, a Hydrodensimeter, also of the surface type, was used on the floor of project culvert No. 1 near Emigrant. Both of these culverts had large empty pockets of empty space in known locations behind the plates, which made them ideal for pilot experimentation with the meters.

Each meter was portable, with a carrying handle on top, and each had a flat base which rests on the ground surface when the meter is used to measure in-place density and moisture content. When readings were taken inside a culvert, the meter was positioned longitudinally in the culvert, with the flat meter base resting against the corrugated plates. A mark on the side of the meter was lined up with a corrugation crest so that the meter always had the same orientation with respect to the corrugation system.

Readings were taken on the floor only of the 3-gage Emigrant pipe-arch. At the 10-gage, 108 inch diameter, Cardwell culvert, readings were also taken on the side walls, almost up to midheight. When this was done, it was necessary for a man to hold the meter in place against the plates. Count times varied from one-fourth minute to a full minute, and all fractional-minute counts were expanded to equivalent full-minute counts so that all readings in a set would be directly comparable.

Counts for both moisture and density were taken at selected locations, where the fill condition or the depth of empty space behind the plates could

be observed directly, from one end of the culvert, or was known from previous punch-hole inspections.

Table 2 gives the results obtained at the Cardwell culvert. The first two sets of readings were taken with the meter resting on top of the 108-inch diameter culvert, at the inlet, and may therefore, be regarded as practical minimum possible readings, for this meter, on a 10-gage plate, with an "infinite" void space below. The table shows that any one-minute density count of less than 10,300 definitely indicated several inches or more of empty space behind the plates, while any density count above 14,000 was indicative of intimate contact between the soil and the culvert. Moisture counts of 400 or less, indicated either a fairly dry soil or several inches of empty space. Moisture counts of 800 or more, were indicative of wet soil with little or no empty space.

It was concluded that the meter was easily capable of detecting the presence of sizable empty pockets behind thin-gage culvert walls, but it is far too heavy and cumbersome to seriously consider it as a feasible tool for even a small amount of routine culvert inspection work.

The results of the survey conducted with a Hydrodensimeter on the floor of the badly undermined Emigrant culvert, which was constructed of 3-gage plates, are given in Table 3. The moisture count and density count trends are seen to be the same as those observed in the Cardwell culvert, and it is apparent, from the tabulation, that void spaces of six-inch depth

TABLE 2 SURVEY OF THE CARDWELL CULVERT WITH A NUCLEAR-CHICAGO SURFACE MOISTURE-DENSITY METER

Location	Equivalent one-minute moisture count (slow neutron backscatter)	Equivalent one-minute density count (gamma photon backscatter)	Approximate depth of void pocket behind plates inches	Remarks
A	36	5409	108	A and B readings were taken with the meter resting on top of the 10-gage, 108 inch diameter culvert, at the inlet.
B	34	5548	108	
C	312	7470	30	Probed through punched hole, 76 feet from outlet.
D	416	10,008 and 10,280	24-30	Probed through punched hole 68 feet from outlet.
E	320	10,146	4	By outside inspection, near inlet.
F	332	12,262	1/2	By outside inspection, near inlet.
G	1006	11,830	1	Soft wet silt, 35 feet from inlet.
H	628	13,772	1	Gravelly Silt, 18 feet from inlet.
I	820	13,300	0-1	Very loose silt, near middle of culvert.
J	972	13,900	None	Stony silt, near middle of culvert.
K	1064	14,300	None	Stony silt near middle of culvert.
L	1012	14,200	None	Stony silt, near middle of culvert.
M	428	14,460	None	Relatively dry hard silt, near the inlet.

TABLE 3 SURVEY OF FLOOR OF EMIGRANT PIPE-ARCH WITH A SURFACE HYDRODENSIMETER

Location	Equivalent one-minute moisture count (slow neutron backscatter)	Equivalent one-minute density count (gamma photon backscatter)	Approximate dapth of void pocket under floor, inches	Remarks
A	98	21,715	12	In undermined region near outlet.
B	103	20,877	12	In undermined region near outlet.
C	134	21,824	12	In undermined region near outlet.
D	117	22,435	12	In undermined region near outlet.
E	239	24,266	6-12	Near edge of empty pocket.
F	242	24,191	6-12	Near edge of empty pocket.
G	420	26,807	None	Over wet rocky soil but very close to edge of empty pocket.
H	1202	30,097	None	Over wet rocky soil about a foot from edge of empty pocket.
I	1401	29,914	None	Wet stony soil.
J	1538	29,892	None	Wet gravelly silt.
K	345	29,060	None	Dry rocks under floor near outlet.
L	945	29,693	None	Wet silt.
M	950	29,250	None	Wet silt, near M.
N	548	28,156	2	Saturated soil under shallow pocket.
O	703	28,376	2-3	Saturated soil under shallow pocket.
P	467	26,327	3	Saturated soil under shallow pocket.
Q	105	24,909	6	Small empty pocket between dry rocks near outlet.

or greater are easily discernible with the Hydrodensimeter. Where there were large empty pockets beneath the floor, the one-minute density counts fell between 20,000 and 25,000. Where the floor was in contact with soil or rock, the density counts exceeded 29,000, except at location G which was close to a large empty pocket. This meter, like the preceding one, was too heavy and cumbersome to be considered feasible for routine culvert inspection, but it was not difficult to use on the relatively flat and dry floor of the Emigrant pipe-arch.

The two pilot studies were highly successful. They demonstrate that nuclear meters may have a great untapped potential for culvert inspection -- a potential that awaits only the development of suitable specialized hardware specifically designed for usage in structural plate culverts. The meters employed were never intended for any kind of use inside culverts, yet they indicated the presence of empty space behind the plates in an effective fashion. In fact, from the very encouraging pilot results, it appears appropriate to speculate that a meter might be developed to accurately measure the density and moisture content of the backfill, right through the culvert walls, in addition to the easier task of merely detecting the presence or absence of backfill material.

Steel plates have a negligible effect on neutrons, so the culvert walls do not appear to be a serious obstacle to the measurement of soil moisture content by the slow neutron backscatter technique. With regard to density

measurements, the culvert walls do initiate a significant amount of gamma photon backscatter, but apparently not enough to mask the reaction from the soil. A standard correction for each different plate thickness could seemingly be determined and applied as part of the measurement process.

It is strongly recommended that research be undertaken to develop a nuclear moisture-density meter for use inside structural plate culverts. The base of the meter could be shaped to match the structural plate corrugations and permit placement of the radioactive source, and the backscatter detector, in the most desirable locations possible. Other primary requisites, for the proposed meter, would be easy portability and provisions for anchorage against sloping culvert walls.

Many culvert problems are traceable to inadequate backfill compaction; and the mere presence, at a construction site of a meter capable of measuring soil density through the walls of a culvert, would undoubtedly enhance the chances of the backfill receiving adequate compaction.

If an inspector could walk into a culvert, at any time, and check the compaction of culvert backfill soil that had been placed days, or even weeks earlier, there would, without doubt, be an improvement in the general level of backfill compaction and a consequent reduction in the frequency of related problems such as piping and structural distress.

PIPING OR INTERNAL EROSION

Water seeping through soil exerts drag forces on the soil grains.

These forces act in the direction of the seepage flow and, if sufficiently large, may dislodge and erode away soil particles at a spot where the seepage water emerges from the soil. As each particle is dislodged and carried away, a concentration of flow, or channelization, occurs, which intensifies the erosive effect and results in the formation of a hole, or piping channel, which works its way upstream through the soil from the point of emerging seepage where it started.

Once piping gets started, its self-accelerating nature may enable it to rapidly undermine a dam or penetrate an embankment and cause a complete washout of the structure. The problem is particularly acute adjacent to outlet pipes buried in earth dams. Here the problem is minimized by careful compaction control and by placing cutoff walls or diaphrams at intervals along the length of the pipe.

In highway embankments, where seepage pressures are typically much smaller than in dams, piping adjacent to culverts has not generally been regarded as a serious problem. However, the large culvert inspections in Montana revealed that piping occurs at culvert installations with sufficient frequency to make it a problem of major practical importance.

Table 4 gives data on four culvert installations where serious piping was found. The O'Keefe and Chester culverts were not among the fifty-five project culverts, but they were studied in addition because of their severe piping.

TABLE 4 DESCRIPTION AND LOCATION OF CULVERTS WITH PIPING

Culvert	Project Culvert Number	Year Installed	Type and Size	Gage	Highway No.	County	Creek Name	Project No. & Description of Location
Emigrant	1	1958	SPPA 16'-7" x 10'-1"	3	89 Alt.	Park	Eight-mile	F 217 (10) 3.5 mi N of Emigrant
Cardwell	6	1957	SPPE 108"	10	359	Madison	---	S 167 1.1 mi S of Jefferson Island
O'Keefe	---	---	RCP 48" double	--	10	Missoula	O'keefe	7 mi N.W. of Missoula
Chester	---	---	SPPA 8'-7" x 5'-11"	12	County Road	Liberty	---	6 mi S. of Chester just E of Jct with Highway 223

Remarks: SPPA refers to structural plate pipe-arch
SPPE refers to structural plate pipe-ellipse
RCP refers to reinforced concrete pipe

Emigrant Culvert (Project Culvert No. 1)

The Emigrant culvert, a pipe-arch, had no visible evidence of piping when it was first inspected in the summer of 1963. However, the culvert was undermined at the outlet, as shown by Figure 6 earlier in this report, and water was flowing out from under the culvert. The outlet end was sagging, and supporting itself by cantilever beam action because it was completely undermined for a length of about fifteen feet. The culvert was badly deformed, and the plates at the bolted seam in the.haunch or corner region, on the left side (when facing downstream), where cracked, throughout almost the full length of the culvert. The left side of the culvert floor was also lower than the right side over most of its length.

A major clue, to explain the acute structural distress of this culvert, was found in the summer of 1964 when holes were punched in the walls and floor to investigate the backfill condition. A large cavity was discovered along the left side of the culvert, behind the cracked plates, for almost the full length of the culvert. This empty space, which was unquestionably caused by piping, greatly reduced the lateral and vertical support on the left side. The cracked plates on that side were undoubtedly the result of excessive bending, caused by the lack of lateral support which permitted the culvert to bulge laterally.

The approximate boundaries of the piping channel, as traced out by the 1964 punch-hole survey, are shown in Figure 35.

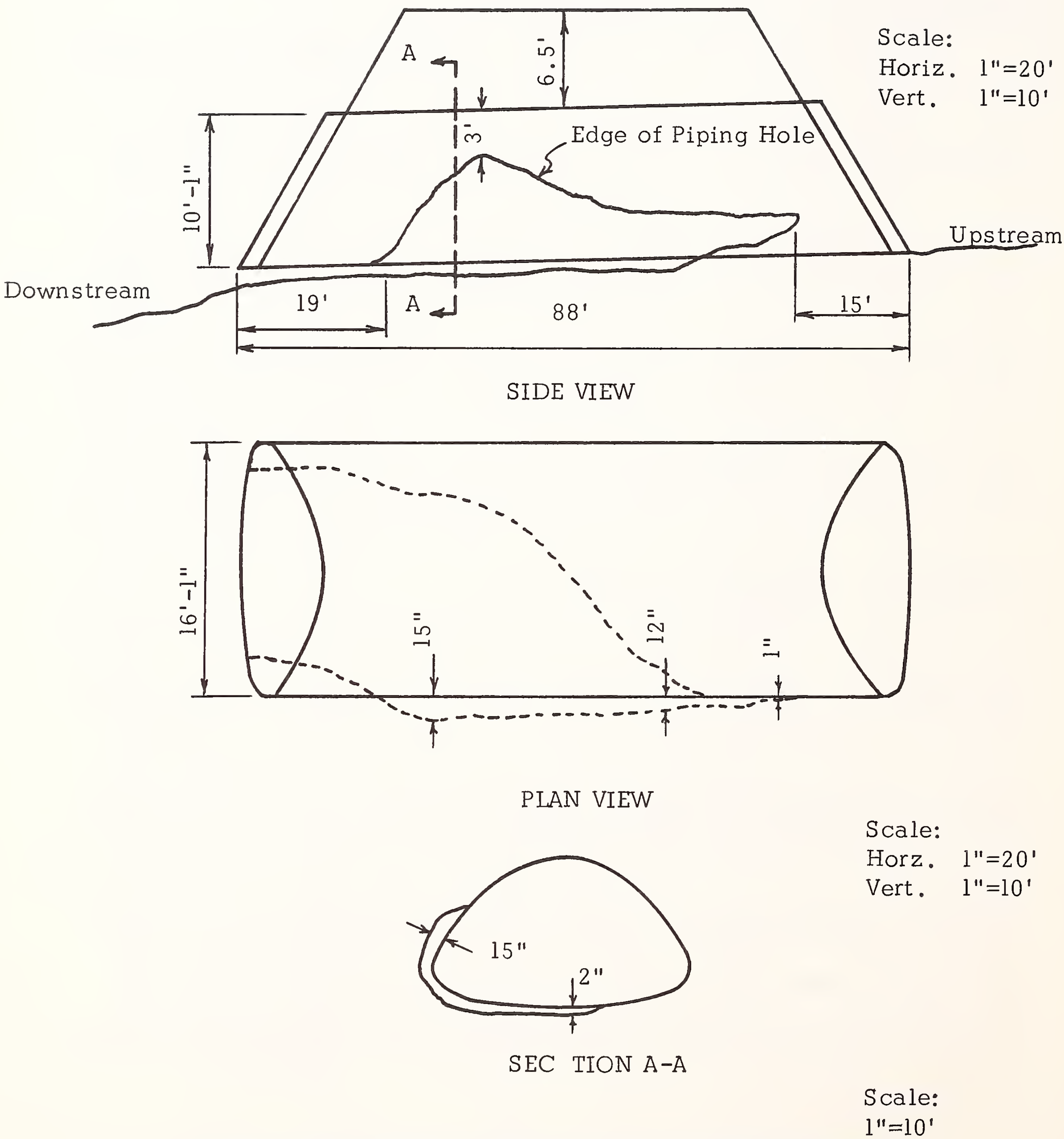


FIGURE 35. PIPING CHANNEL AT EMIGRANT CULVERT

The floor was intermittently supported on gravel or cobbles in the piping region shown. The left wall had one big void space behind it, varying in size as shown above.

The man who was the project engineer, when the culvert was constructed in 1958, was interviewed; and he stated that the contractor had done a very good job and that careful inspection had been maintained. He also said that high water occurred, shortly after construction, before the pavement had been placed, and washed away some sandy backfill material and bedding material on the left side, causing a "failure" which consisted of excessive settlement of the culvert and the overlying fill. A highway department maintenance crew "dug out" around the ends of the culvert and placed in new fill material.

Division construction and maintenance personnel were also interviewed, and it was learned that rocks had been placed around the outlet on several occasions in largely unsuccessful attempts to control outlet scour and outlet channel degradation. In 1965, hand-placed rocks were inserted under the undermined outlet to support it, but they were gone by the summer of 1966. The pavement above the culvert settled more-or-less continuously and required frequent maintenance.

No one reported seeing cracked plates in the culvert prior to 1963 when they were discovered by research project personnel; and nobody recalled seeing a piping hole on the left side of the culvert when the ends were "dug out" and refilled.

It is suspected that the large piping hole was formed by the high water that occurred shortly after construction and that it was visible to the

maintenance personnel who "dug out" and replaced part of the embankment. If it was seen, it apparently was dismissed as insignificant, covered up, and forgotten, with no realization of the threat that it posed to the culvert.

The condition of the Emigrant culvert continued to deteriorate. The cracks in the cracked plates became noticably larger, and the culvert continued to compress vertically and bulge laterally as revealed by the height and width measurements shown in Table 5. The table shows that the width increased approximately 1/2" and the height decreased approximately 7/8", between August of 1964 and July of 1966. To prevent a total collapse, the culvert was removed and replaced in 1967.

Cardwell Culvert (Project Culvert No. 6)

A well-developed piping hole was discovered along the right side of the 108-inch diameter Cardwell culvert when it was first inspected in the summer of 1963. At the outlet end, the hole was just barely large enough for a man to crawl into, but it was apparent that the hole had been much larger and had been partially filled by sluffing and caving-in of the highly erodible silt embankment soil. At the inlet end, the piping hole was hidden by tall weeds, and it was found only after a diligent search. After the weeds were pulled away, it was plainly visible. Pictures of the inlet and outlet of the hole are shown in Figure 36, and a profile sketch of the piping channel is shown in Figure 37.

TABLE 5 HEIGHT AND WIDTH MEASUREMENTS OF THE EMIGRANT CULVERT

Shown are clear width and height measurements at marked stations. The original nominal dimensions were 16'-7" span x 10'-1" height.

Sta.	Distance from Inlet	Width or Span		Height	
		August 1964	July 1966	August 1964	July 1966
1	20'	16'-9 1/2"	16'-10"	9'-7 1/8"	9'-6 1/2"
2	28'	16'-11 1/2"	17'-0"	9'-5 1/8"	9'-4 1/4"
3	36'	16'-11 3/4"	17'-0 1/4"	9'-2 2/3"	9'-1 5/8"
4	44' (Middle)	16'-11 1/2"	17'-0"	9'-2"	9'-1 1/8"
5	52'	17'-0 3/8"	17'-0 7/8"	9'-2 5/8"	9'-1 3/4"
6	60'	16'-11'	16'-11 5/8"	9'-3"	9'-2 1/4"
7	68'	16'-10"	16'-10 5/8"	9'-6"	9'-5 3/8"

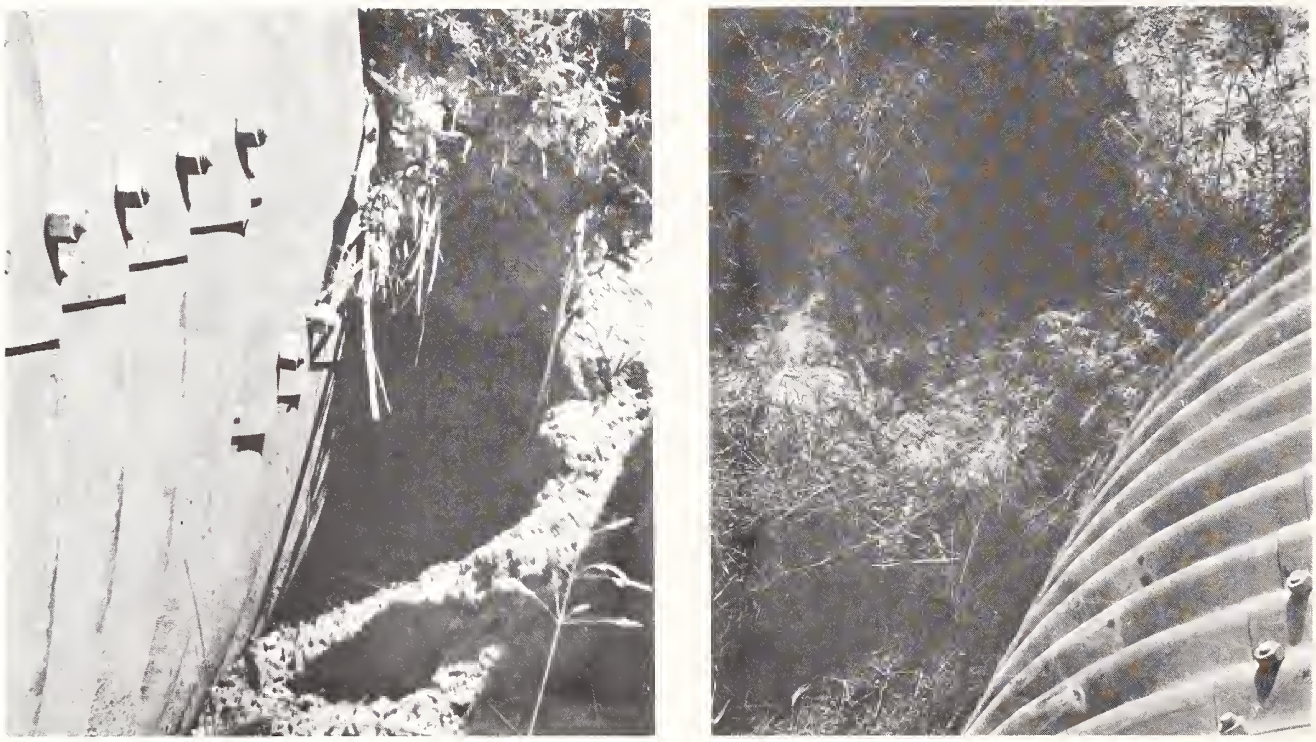


FIGURE 36. INLET AND OUTLET OF PIPING HOLE AT THE CARDWELL CULVERT

The picture on the left shows the inlet piping hole which extended back as far as could be seen with a flashlight. The picture on the right shows the outlet piping hole which was large enough for a man to crawl into.

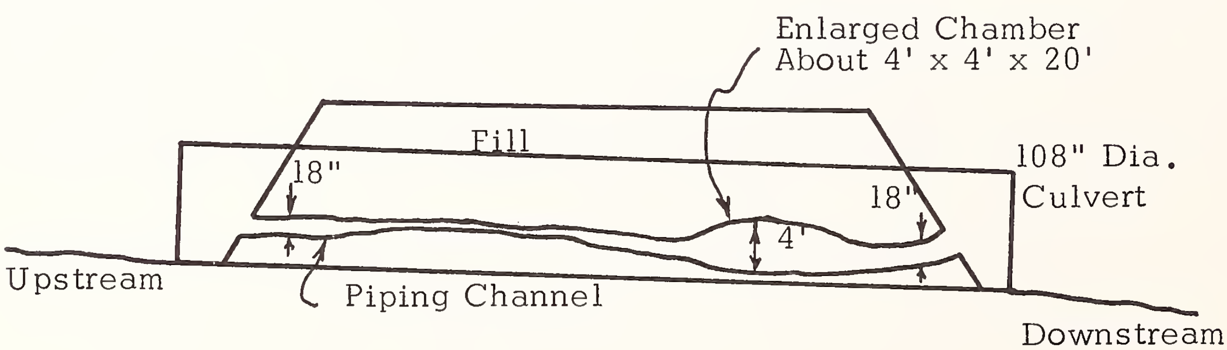


FIGURE 37. SKETCH OF CARDWELL PIPING CHANNEL

Shown is a profile section of the piping channel along the right side of this culvert.

With the aid of a flashlight, it was possible to see about fifteen feet into the hole at the inlet and thirty feet or more at the outlet. The piping channel was traced out for the full length of the culvert, with a Schmidt Hammer; and its presence near the middle of the culvert was also verified by holes that were punched in the culvert wall.

According to a farmer who lives about one hundred yards from the Cardwell culvert, piping developed in 1958, the first year after installation, and has become progressively worse. He also stated that the backfill soil at the sides of the culvert was sprinkled with water and tamped with air hammers, during construction; and that flood water had never been as high as midheight on the culvert at the inlet. This indicates that piping can develop under low headwater conditions.

The Cardwell culvert, unlike the Emigrant culvert, has not exhibited any structural distress as a result of partial removal of lateral support by piping. The embankment soil above and below the piping channel is still apparently providing adequate lateral support to the culvert.

The visual appearance of the culvert remains very good. It was installed as an ellipse, 117 inches high by 99 inches wide. Near midlength it has deflected to an almost circular shape, 109 inches high by 107 1/2 inches wide. There has not been any perceptible deflection change between 1963 and 1967, and the pavement above the culvert has shown no sign of differential settlement. However, there has not been any high water at the site during that period to aggravate the situation.

In 1965, county maintenance forces covered each end of the piping hole with rocky, silty, backfill material, but it is suspected that this will not effectively curtail piping at the site. The next heavy flow of water is likely to reopen the piping hole and enlarge it still further.

O'Keefe Creek Culvert

The O'Keefe Creek culvert installation, seven miles northwest of Missoula on old U.S. Highway 10, consists of a pair of four-foot diameter reinforced concrete pipes that were installed only a few inches apart in a clay soil having a plasticity index of 23.

When the installation was first observed, in the summer of 1963, there was a very prominent piping hole between the pipes at the outlet. The lower picture of Figure 38 shows the inspector looking into this hole. Inside was a large empty chamber about six feet high and twenty feet long, where the soil was washed completely away from beneath each pipe for a length of about ten feet. The beam strength of the pipes permitted them to bridge this gap without any apparent distress. Piping holes were also visible at each side of the pipes, at the outlet, when the weeds were pulled away.

The top picture of Figure 38 shows the inlet end of the culvert, where piping holes were also present on each side. They do not show up well in the picture, however. Between the pipes, at the inlet, there was a

FIGURE 38. INLET AND OUTLET OF THE O'KEEFE CULVERT, 1963

In the picture at the top, notice how the fill between the culverts has settled. The picture on the left shows the piping hole between the pipes at the outlet.

trench-like depression which extended up the side of the fill slope, almost to the top of the embankment. It is theorized that this depression was formed as a result of the embankment soil collapsing into a large piping channel similar to the one that was still open at the outlet.

State maintenance forces have taken steps to partially correct the situation. The pipes have been encased in a concrete headwall at the inlet; also, a large amount of dirty pit-run gravel, with cobbles and boulders, has been placed at the inlet, and between the pipes at the outlet. Rocks have also been hand-placed beneath the outlet to support the end sections.

Figures 39 and 40 show the inlet and outlet of the installation as they appeared on July 14, 1967. The large piping hole between the pipes at the outlet had been covered up, but piping holes were still visible on each side of the outlet, when the weeds were pulled away. One of these piping holes shows up well in Figure 40, at midheight on the right-hand side of the right-hand pipe in the photograph.

It appears that piping will continue to occur at this site if flood water gets high enough to submerge the inlet by several feet.

Chester Culvert

The Chester Culvert, which was installed on a county road, in a silty clay soil having a PI of 12, is shown in Figures 41 and 42, as it appeared in July of 1964. There was a large piping hole on each side of the inlet and several small piping holes were visible underneath the badly undermined outlet.

FIGURE 39. HEADWALL AT THE INLET OF THE O'KEEFE CREEK INSTALLATION, JULY 1967

FIGURE 40. OUTLET OF THE O'KEEFE CREEK CULVERT INSTALLATION, JULY 1967

FIGURE 41. OUTLET OF THE CHESTER CULVERT IN JULY, 1964
Piping holes are under the outlet.

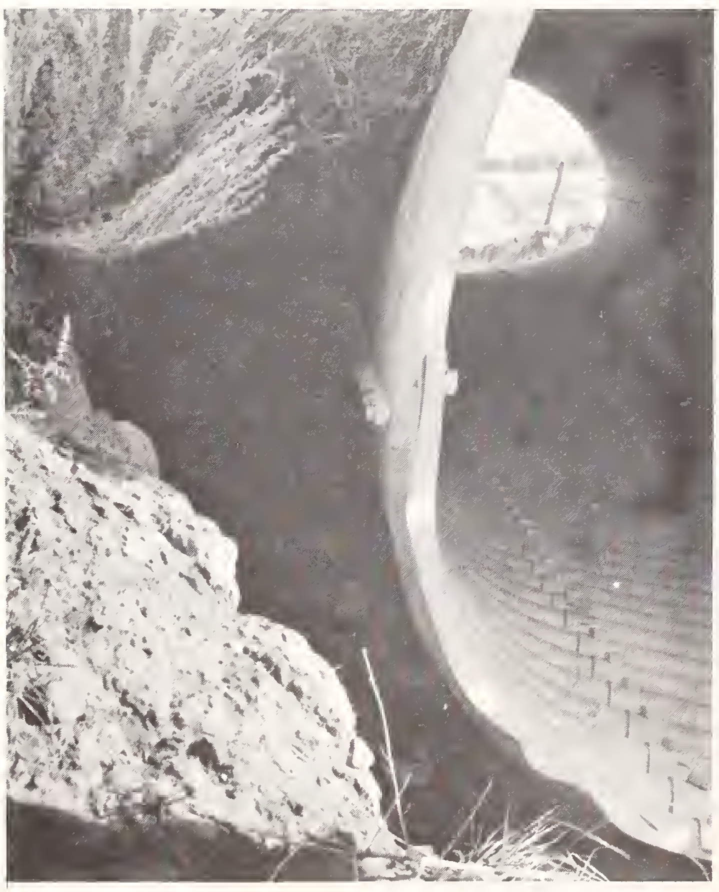


FIGURE 42. A LARGE PIPING HOLE ON THE LEFT SIDE OF THE INLET OF THE CHESTER CULVERT IN JULY, 1964.

There was a similar piping hole on the right side of the inlet.

The Liberty County Commissioners were informed of the condition of the culvert, and it was recommended to them that the culvert be partially dug out and the clay fill packed back in around the culvert. Something of this sort was finally done, but not until the condition of the culvert had become much worse than it was in 1964. When the culvert was last inspected in June of 1967, it was apparent that a large amount of clay had recently been placed around the culvert at each end. The degraded downstream channel had also been filled in with clay, up to the level of the culvert floor.

At the time of the 1967 inspection, the culvert was badly deformed, especially the floor which was bulged markedly upward in several places. Measurements taken near the worst spot, near the middle of the culvert on June 29, 1967, gave a width of 8' - 11 3/4" and a height of only 4'-11 1/2". These measurements correspond to a horizontal deflection of +4.6% and a vertical deflection of -16.2%, based on the standard nominal dimensions of 8' - 7" span and 5' - 11" rise. In spite of the excessive deflections, there was no evidence of cracked plates or any other type of seam failure of the Chester culvert.

Discussion

Soil samples from the piping hole regions of the four culverts with advanced stage piping were analyzed, and the results are presented in Table 6. It is apparent, from the table, that piping can and does take place

TABLE 6 CLASSIFICATION OF SOIL SAMPLES TAKEN FROM PIPING HOLE REGIONS

SITE	EMIGRANT	CARDWELL	O'KEEFE	CHESTER
Textural Type	Gravelly Sand	Silt	Clay	Silty Clay
AASHO Classification and Group Index	A-1-b (0)	A-4 (8)	A-7-6 (15)	A-6 (7)
Liquid Limit	NP	29	47	31
Plasticity Index	NP	4	23	12
% Passing #4	67	100	98	98
% Passing #40	38	99	95	92
% Passing #200	12	92	91	64

in a wide variety of soils, ranging from gravelly sand to plastic clay. It is generally agreed, however, that silts or fine sands, with little or no cohesion, are most susceptible to piping.

Of the four soils of Table 6, only the low plasticity silt of the Cardwell site would be classified as highly susceptible to piping. Further evidence of the strong piping tendency of the Cardwell silt was found in the upstream channel and in the embankment side ditches. Just a few yards upstream from the culvert a piping "tunnel", several yards long and almost a foot in diameter was observed in the vertical stream bank. Also, in a side ditch near the culvert inlet, the ditch channel disappeared into a hole of about ten inch diameter and reappeared, several yards downstream and several feet lower, from another hole of about the same size.

A keen observer can find numerous examples of this latter condition, in either silt or clay soils, both in side ditches and on the faces of embankment side-slopes; and they are not always indicative of piping. Narrow surface erosion gullies are sometimes bridged over by the sluffing or sliding of small masses of adjacent soil, and these "covered" gullies are sometimes virtually indistinguishable from bonafide piping channels of underground origin. In a few cases, during the culvert surveys, these small covered gullies were observed right beside a culvert outlet or inlet; and they were initially thought to be piping holes. For example, a hole on one side of the outlet of culvert No. 49, observed in June of 1967, was definitely verified as a covered gully resulting from surface erosion adjacent to the culvert; but it had the appearance of a true piping hole. Also, small holes observed at the outlets of project culverts 46 and 47, in plastic clay soils near

Wolf Point, in 1963 and 1964, were classified as early-stage piping at that time; but they could not be traced more than a couple of feet back into the embankment at that time, and it is theorized that they may have holes of the covered gully type. There was no sign of them when the Wolf Point culverts were inspected in June of 1967.

Cohesive clay soils are virtually impervious, when well-compacted, and are highly resistant to piping when in that condition unless cracks, subsidence gaps, or other small, open, discontinuities exist to permit an initial easy path for the rapid flow of seepage water which can readily enlarge its channel after a low resistance flow path is found. Of course, if the backfill soil is inadequately compacted, or not compacted at all, serious piping could develop almost instantaneously.

There is prima facie evidence that a lack of compaction played a role in the O'Keefe Creek piping case. In that case, the twin pipes were installed so close together that it would have been virtually impossible to compact the clay between the pipes, below mid-depth, in the haunch region. The reader is referred back to Figures 38, 39 and 40 for pictorial evidence of this point.

There is no evidence that improper compaction had anything to do with the Chester piping case, where the soil was a low=plasticity clay. However, the Chester culvert is situated on a lightly traveled county road where one would expect generally poorer compaction control than on a state highway.

Piping can occur in any type of fine-grained soil if it is not adequately compacted. A fine-grained soil which has been tamped, and has a uniform firm appearance, may still pipe readily if its density is insufficient to prevent it from experiencing slaking, skeletal collapse, and consolidation, when it

becomes saturated. This can happen quite easily with some sandy or silty soils; and it can also happen with lumpy clay that has been tamped at too low a water content.

Model studies of seepage and piping adjacent to a 12-inch diameter corrugated metal outlet pipe, in a small earth dam, were conducted for the Bureau of Land Management, by the Bureau of Reclamation, and reported in 1958 (9). The soil used was described as a "sandy clay, reddish brown, about 50% sand, slightly plastic". It had a liquid limit of 23, and a plasticity index of 9, which makes it an A-4 (3) soil, but almost an A-6 (3), by the AASHO classification system. One of the major conclusions from this set of model studies was that this particular soil had to be compacted around the pipe to a density of at least 95% of Proctor maximum (Bureau of Reclamation version) to prevent seepage from developing and jeopardizing the installation by piping. A 3'x3' cutoff diaphram, at midlength, was not effective in preventing piping when the soil was placed at lesser densities.

It appears that the enforcement of stringent compaction specifications, to insure a high degree of compaction all the way around a pipe, might be justified solely on the basis of the reduced danger of piping, not to mention the more immediate and direct structural support benefits which are usually quoted as the reason for requiring a highly compacted backfill. However, compaction alone will not eliminate the danger of piping in silty or sandy soils of high susceptibility.

Shallow cutoff walls, which are now required at large culvert installations on state highways in Montana, will help to minimize the piping problem and the loss of granular bedding material, but they are not a cure-all either. At the Cardwell culvert, it appears that cutoff walls would have done little, if anything, to prevent the existing case of piping because the piping channel is almost entirely above the level of the top of a standard cutoff wall.

Research should be undertaken to determine inexpensive and effective means of inhibiting piping at culvert sites in highly susceptible soils such as the Cardwell silt. Conceivably, a series of cutoff diaphrams, like those used on outlet pipes in earth dams, might be justified in certain extreme cases.

In theory, at least, the danger of piping at a culvert site could be eliminated by providing a graded filter, of the proper dimensions, at the outlet end, utilizing the well-known Waterways Experiment Station gradation requirements. Each filter layer must be fine eoungh to prevent migration of the finer material immediately upstream, but coarse enough to drain freely and prevent dangerous seepage pressures from building up. The first requirement is satisfied if the 15 percent size of the filter is not more than four or five times larger than the 85 percent size of the finer material immediately upstream. To satisfy the second requirement, the 15 percent size of the filter should be more than four or five time larger than the 15 percent size of the adjacent finer soil.

The 15 percent size and the 85 percent size, for a particular material, may be picked directly from its gradation curve. Specifically, 15 percent, by weight, of the material, is smaller than its 15 percent size, and 85 percent of the material is smaller than its 85 percent size.

Figure 43 shows a hypothetical filter system that should, theoretically, prevent piping of a fine-grained embankment soil if the filter requirements stated previously are satisfied between each layer and its adjacent upstream layer. A thickness of two feet should be adequate for each filter layer.

An attempt to study culvert seepage and piping problems quantitatively, with the use of flow nets, would require so many simplifying assumptions that the results would be of no practical use. The lack of watertight joints in culverts is one of the complicating factors and it is also a factor that aggravates the piping danger. If culvert seams were watertight, and if there were no significant internal channels within an embankment to concentrate the flow, then the energy of the seeping water would be dissipated in a safe and gradual manner as it seeped the full length of the culvert, through the small pores of the embankment soil. However, in a culvert with leaky joints, water may flow inside the culvert for almost its full length with very little energy loss and enter the soil under high pressure, through a leaking seam, within only a few feet or a few inches of the outlet.

Under the conditions posed above, piping might start at the outlet end, at a leaking seam, in a soil that would otherwise be highly resistant to

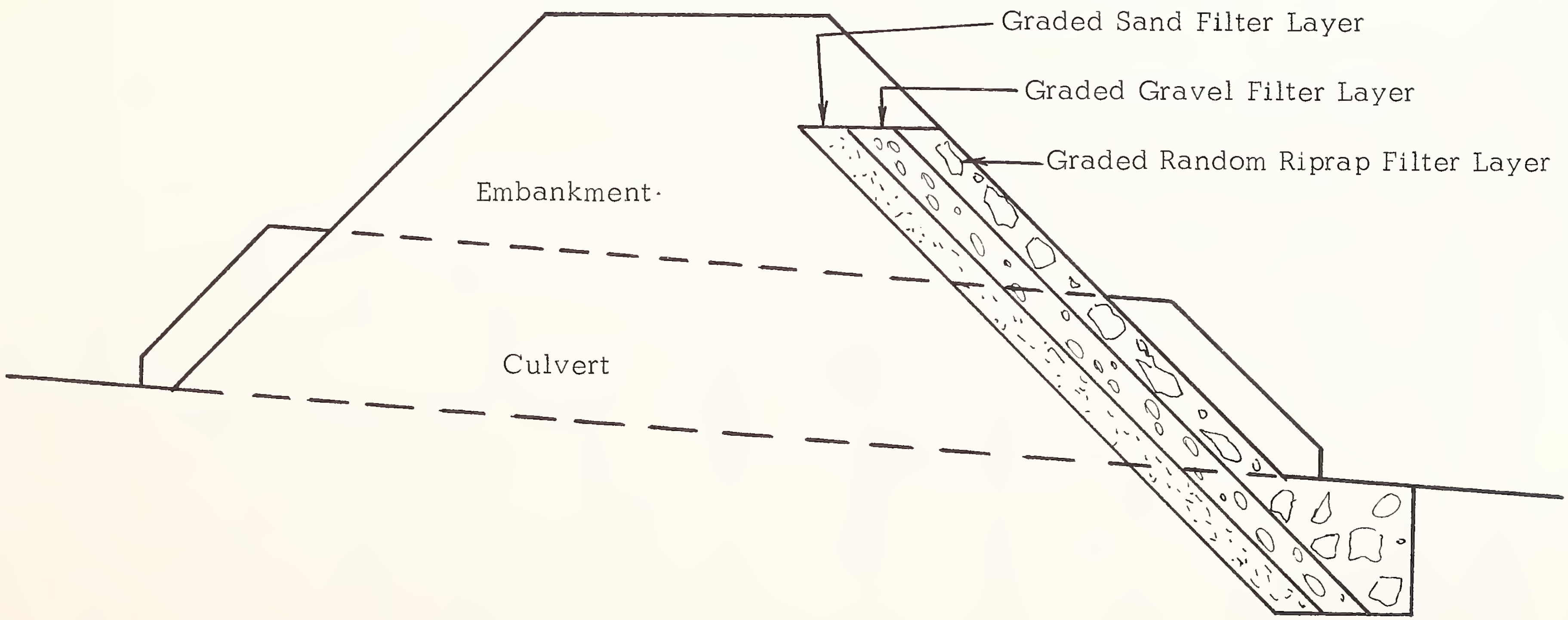


FIGURE 43. A HYPOTHETICAL CULVERT OUTLET FILTER SYSTEM TO PREVENT PIPING OF A FINE-GRAINED EMBANKMENT SOIL.

piping. A piping channel could then work its way upstream through the embankment, along the leaking seam, for the full length of the culvert. In a qualitative sense, the problem is easy to understand, but it is impossible to make a reliable quantitative estimate of the extent to which leaking seams initiate piping. Early-stage piping should be suspected when one observes a small hole in the soil, at a culvert outlet, near a longitudinal seam.

The cost of water proofing the seams of all structural plate culverts could not be justified because most culverts perform very well without waterproof seams. However, there is a need for future research to determine where and when water tight seams are necessary or desirable, and to determine effective and economical means of providing the necessary degree of watertightness. The effectiveness and feasibility of impervious clay cutoff bankets or walls should also be investigated.

How best to correct or eliminate a case of piping, once it has been diagnosed, is another problem that deserves attention. To cover up the ends and leave the middle untouched, as was done at Emigrant and also, more recently, at Cardwell, O'Keefe Creek and Chester, is a practice that cannot be recommended. At Emigrant, the reduced lateral support brought the culvert to the verge of total collapse in spite of the fact that there had been no recent high water to intensify the problem.

Any competent method for correcting a case of piping must include provisions for eliminating the piping channel or channels. This is necessary,

both to restore needed structural support to the culvert, over its entire length, and to prevent a rapid resumption of piping with the next unusually high water.

In any case, it would seemingly be feasible to dig out the inlet and outlet ends of the culvert, for a length of perhaps 10 feet, and carefully rebackfill the ends, preferably with a material less susceptible to piping than that removed. It appears that a relatively impervious clay would be a particularly good choice of material for the rebackfilling job, especially at the inlet end. After refilling the ends, the remaining central section of the piping hole could then be filled by pressure grouting after first strutting the culvert to prevent it from distorting excessively under the pressure of the grout.

Talks with maintenance personnel and others, throughout the state, made it clear that there was not a general awareness of the threat that a piping hole poses, either with respect to the complete washout danger or the danger of structural collapse through the loss of earth support. Another interesting aspect of these talks is that a few individuals recalled having seen one or more severe cases of piping in the past. In one case "a big patch of daylight" was reportedly visible, all the way through the fill.

It is concluded that piping has not been and is not now a particularly rare phenomenon at large culvert installations in Montana. Although only four cases of severe piping were observed while inspecting approximately 400 large culverts, it would be optimistic to assume that only one percent of the

state's large culverts are affected by piping. Some cases could have been overlooked where the ends of the hole had been covered up. Initially, this was the case at the Emigrant culvert where piping was not discovered until holes were punched in the culvert walls to investigate the backfill condition. Furthermore, one could theorize that quite a few culverts that develop a problem as serious as piping do not last long enough to be counted at some later date.

There is no way of known how many culverts develop piping and wash completely out during moderate floods that would not have caused any significant culvert damage if piping had not occurred.

In the absence of piping, it could be assumed that a culvert will usually be safe from washout unless flood water overtops the embankment. With piping, however, the first hint of danger might come with a sudden catastrophic collapse of the road surface into a piping hole that developed from a relatively minor flood that never came close to making water run across the road. Unfortunately, the frequency of such occurrences remains a matter of speculation.

The obvious way to shed some light on the subject would be to interview eye-witnesses of culvert washouts. Such persons are hard to find, however. In the long run, a useful file of information on the subject could be obtained by studying each new washout site to determine whether or not flood water overtopped the embankment before the culvert washed out.

Headwater pool levels insufficient to put flood water across the road could be considered as prima facie evidence of piping, except at sites where water running parallel to an embankment might have eroded it away without either piping or overtopping.

It is unfortunate that piping holes at culvert outlets or inlets tend to be highly inconspicuous, even when they are not completely hidden by vegetation, large boulders, or other objects. Large single-size rock riprap, which cannot prevent piping from taking place through its large void spaces, can do an especially effective job of hiding visible evidence of piping. Tall grass, weeds, or tumbleweeds, can also hide the ends of piping holes very effectively, but these can be pulled away by a conscientious culvert inspector.

Maintenance personnel should be made aware of the serious threat to culverts that piping holes represent. They should be instructed to look for them, following high water, and report any that they find to their supervisors. An untrained worker can hardly be blamed for covering up the end of a piping hole with a truckload of rocks, and then forgetting about it, if he has not been instructed to the contrary.

CRACKED PLATES

Under heavy bending loads, the plates of structural plate culverts sometimes fail by cracking at longitudinal seams. The cracks originate at bolt holes, on the flexural tension side of a seam, and radiate outward longitudinally toward the adjacent crests or valleys where the plates are in

flexural compression. If the cracks terminate in the compression zones, the seam will still function structurally, but only as a hinge, with virtually no resistance to further bending. In an extreme case, the cracks may join up or meet midway between bolts and thereby effect a complete plate separation or fracture along the seam.

In an affected culvert the cracks may be so inconspicuous that they are easily overlooked by an inspector unless he makes a conscious search for them. The appearance of the cracked seam shown in Figure 44 may be considered typical.

During the culvert inspections of 1963-64, cracked plates were found at eight culvert installations. Three of these were double installations in which both barrels were cracked. Table 7 gives pertinent information on the cracked culverts.

It is highly significant that all but one of the affected installations are pipe-arches, and that they are cracked along the seam at the top of the 18-inch radious corner plates.

Excessive bending moments are generated in the corner regions of pipe-arches unless the lateral earth support is particularly firm and unyielding. In circular or elliptical culverts, the generated moments will be smaller, and the needed lateral earth support can be mobilized easier because the pipes can bulge farther, laterally, without serious structural consequences. In a pipe-arch, the relatively flat floor acts like a tie and limits the extent to

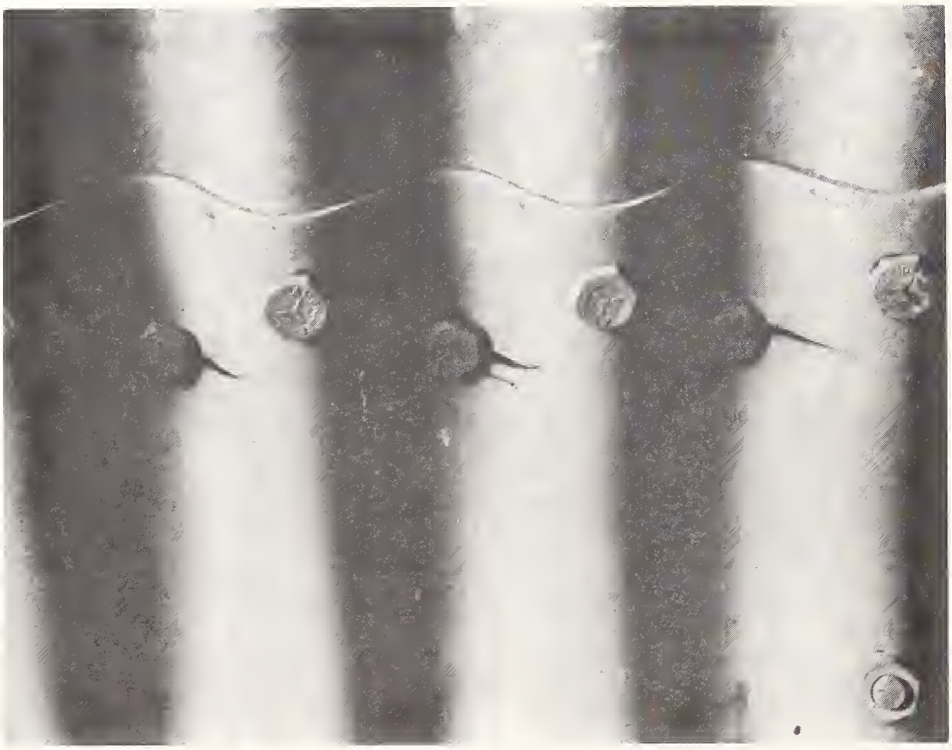


FIGURE 44. CRACKED PLATES IN THE EMIGRANT CULVERT (PROJECT CULVERT NO. 1)

TABLE 7 CULVERTS WITH CRACKED PLATES

Project Culvert Number	Location	Type and Size	Gage	Depth of Cover, Feet.	Vertical Deflection, % of Height	Horizontal Deflection % of width	Location of Visible Cracked Plates	Remarks, 1967
1	3.5 mi N of Emigrant on U.S. 89	SPPA 16' - 7" x 10'-1"	3	6 1/2	-9	+3	Seam at top of 18" radius corner plates, left side.	On verge of collapse. Cracks wider and deflection worse than in 1964. Pavement patched.
7 A	Victor Chem. Plant Road near Butte	SPPA 12' - 8" x 8'-1"	7	Variable	-42	+6	Seam at top of corner plates, both sides; also floor seam.	Practically collapsed; floor buckled upward; plate separation at floor seam. Worse since 1964.
29	4 mi. E of U.S. 89 towards Martinsdale	SPPA 11' - 10" x 7'-7"	8	2	-4	+1	Seam at top of corner plates on left side.	Apparently stable; same as 1963; pavement above ok.
36	1 mi N of Suffolk	SPPA Dbl. 12' - 6" x 7'-11"	8	5 1/2	--	+4	Seam at top of corner plates on one side; both pipes.	Apparently stable; same as 1963; pavement above ok.
37	1 mi S of Winifred	SPPA Dbl. 14'-1" x 8'-9"	7	7	-10	+4	Seam at top of corner plates on one side; both pipes.	Apparently stable; same as 1963; pavement above ok.

continued on next page

Table 7 (continued)

Project Culvert Number	Location	Type and Size	Gage	Depth of Cover, Feet	Vertical Deflection, % of Height	Horizontal Deflection % of width	Location of Visible Cracked Plates	Remarks, 1967
44	9 mi SW of Richey on Mont 20	SPPE 12'-0"	8	22	-8	+12	Side seams on both sides in both pipes.	External appearance ok; high water prevented inside inspection in 1967; obvious dip in pavement.
--	1.5 mi E of Galata on U.S. 2	SPPA 10' 3" x 6'-9"	8	15	Excessive, mud prevented measurement	Excessive, mud prevented measurement	Seam at top of corner plates on right side.	Large height of cover. Dip in pavement has been extensively patched.
--	2.7 mi E of Galata on U. S. 2	SPPA 10' 3" x 6'-9"	7	20	-15	+6	Seam at top of corner plates on right side.	Excessive height of cover. Dip in pavement has been extensively patched.

which the sides may bulge harmlessly outward to pick up lateral earh support. Large bending moments are also generated in the invert region and give the invert a tendency to bulge or buckle upward. This tendency is accentuated when a corner seam cracks, degenerates to a hinge, and transfers additional moment to the invert.

When the floor of a pipe-arch bulges or buckles upward, the floor seams in the invert region may crack or rip; but the plate damage sometimes occurs only on the bottom side of the floor seam where it is not visible from inside the culvert. The floor of the Emigrant culvert, the first culvert listed in Table 7, was bulged up several inches in one spot. A seam bolt was removed to investigate conditions below. Probing, with fingers and a knife blade, revealed a crack on each side of the bolt hole, in the bottom plate of the simple lap joint.

The sense of the bending moment, and the plate lapping arrangement at an affected joint, will largely determine whether or not the cracks that form are visible from inside the culvert. It is suspected that some pipe-arches with visibly cracked plates on one side only, also have cracks, which are hidden from view, at the corner seam on the opposite side of the culvert.

Cracks in the plate on the hidden side of a joint may become visible if there is sufficient joint distortion to expose them. The floor of the second culvert listed in Table 7 (the overflow relief pipe-arch at the Nissler overpass near Butte), is buckled upward so severely that a complete plate separation

has occurred at some of the floor seams. At other floor seams, cracks are exposed that would be hidden by the overlapped plate if the joint distortion was less severe. Figure 45 shows the buckled floor of this culvert as it appeared on July 15, 1967. The width of this culvert, in the failed region, is six percent larger than the nominal standard width. This represents an extremely large horizontal deflection for a pipe-arch and indicates that a deficiency of lateral support might have been the primary cause of the failure. The outward bulging of the sides, coupled with cracking of the corner seams, could readily generate sufficiently large bending moments in the invert region to trigger the upward buckling of the floor. The floor is also in direct tension because it acts as a tie for the arch above, and this has apparently restrained the buckling sufficiently to prevent a complete collapse of the culvert.

Upward buckling of a floor could also be initiated by faulty bedding that leaves the floor inadequately supported on the sides and concentrates the floor reaction along the centerline. The same condition could exist in a culvert that was properly bedded but subsequently lost floor support on the sides through piping of the bedding material.

Ostensibly, a floor that buckled upward, from a centrally concentrated floor reaction, would pull the culvert sides inward. At least there would be no need for the sides to bulge outward significantly in such a case. The large amount of outward bulging that has occurred in culvert 7A is indicative of a lack of rigid lateral support, whether or not one chooses to believe that poor lateral support was responsible for the buckling.

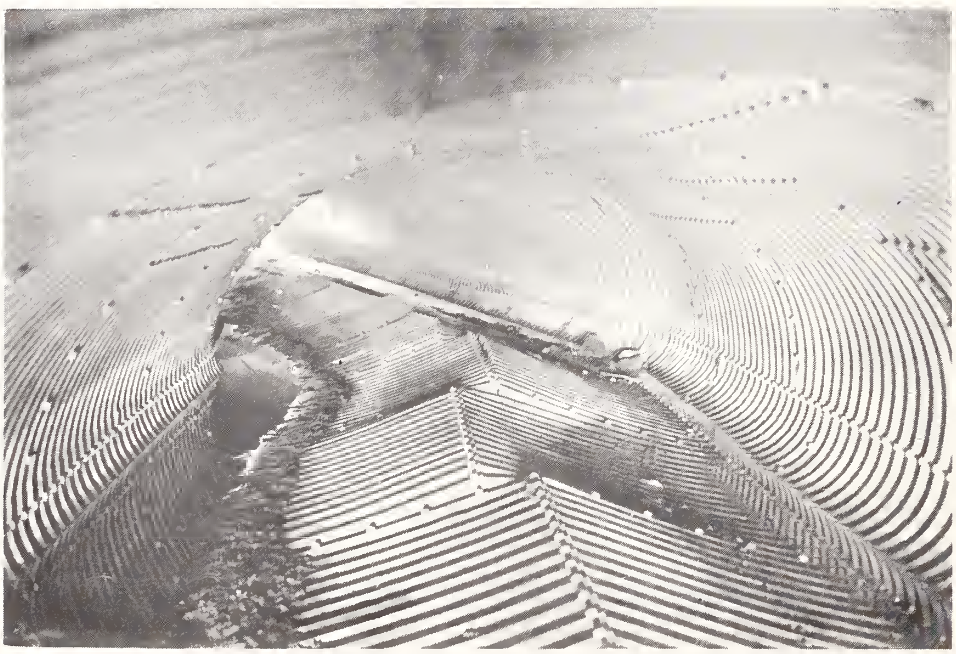


FIGURE 45. BUCKLED FLOOR OF PROJECT CULVERT NO. 7A, NEAR BUTTE

The plates are also cracked along the corner seams on each side.

Since 1964, the distance from the buckled floor to the roof of culvert 7A has decreased by about four inches, and complete seam failures have occurred in four plates. It appears that a total structural collapse is imminent.

It has been recommended that the culvert be strutted vertically and the struts left in place permanently. Hopefully, this would arrest the continuing structural deterioration without too seriously impairing the intermittent and infrequent flood-relief function which is the culvert's only function. The culvert is situated under the sloping side of an overpass embankment, parallel and immediately adjacent to a low railroad embankment that runs under the overpass. The culvert could collapse without affecting the railroad tracks adjacent or the highway above; unless the collapse occurred during a flood, in which case there might be some flood damage to the railroad.

The Emigrant culvert was the only cracked culvert where the cracked plates were definitely associated with the removal of lateral earth support by piping. At one time it was suspected that there might also be hidden piping holes at project culverts 29, 36 and 37 (see Table 7), but the Schmidt Hammer and punch-hole surveys failed to verify this suspicion. However, soft or loose soil, which a probing wire penetrated with relative ease, was encountered at some of the punch holes in each of these culverts. This might lead one to surmise that the backfill was simply not compacted sufficiently to permit it to furnish the necessary lateral earth support. This hypothesis is compatible

with the large deflections of culverts 36 and 37, but it is less satisfactory in regard to culvert 29 which shows very little lateral distortion. Culvert 29 also has a minimal depth of covert, which makes it somewhat more susceptible to damage from heavy wheel loads than the other culverts.

Culverts are sometimes damaged, even completely flattened, by overloads from heavy construction equipment before backfilling reaches a safe height at the sides or top. If a culvert were overstressed and distorted by this type of overload in the early stages of construction, a work crew might restore it to reasonably good shape by pushing it together laterally, or strutting it vertically, before completing the backfilling operations. If skillfully done, this could result in a culvert of good general appearance, with height and width measurements differing but little from the nominal standard dimensions. Unobtrusive cracks at a corner seam could be overlooked by all the persons involved, and perhaps on one would even be aware that structural damage had occurred.

It remains a matter of speculation whether or not any of the plate damage observed at the eight installations was caused by heavy wheel loads during construction or by careless compaction. The construction notes for the affected project culverts gave no indication of any kind of trouble. Personal interviews with division engineers, maintenance men, and others, also failed to turn up any clues.

Project culvert No. 44, near Richey, Montana, was the only cracked culvert found that was not a pipe-arch. There are cracks in the plates at seams on each side of each barrel of this twin elliptical-pipe installation, In the right barrel they extended almost the full length of the culvert. The pipes are now wider than they were tall, originally, but the general overall appearance of the installation remains good. As of June 1967, the pavement above showed no evidence of recent patching, but there was a broad and noticeable dip, approximately six inches in depth, in the road surface.

Deep standing water and swampy end conditions make inside access to this culvert very difficult most of the time. It has not been feasible for research workers to work in it since the summer of 1963. The Schmidt Hammer survey taken at that time did not indicate empty space or unusually soft backfill, but it has not been feasible to make a punch-hole inspection to supplement or verify the Schmidt Hammer data. Neither has it been feasible to attempt any recent height or width measurements to see if the distortion of the pipes is continuing. Judging from external appearances only, the structure has shown no change, since 1963, and appears to be stable. However, the embankment soil is clay which is likely to experience long-term plastic flow and cannot, therefore, be expected to support itself indefinitely by arching over the damaged pipes.

The excessive lateral bulging of the twin pipes proves that the clay backfill did not furnish sufficient lateral support initially to permit the pipes to properly carry the load from the 22-foot height of cover. In a clay embankment of this height, it is especially important that the backfill around a large culvert be compacted to the highest practicable density.

The last two culverts listed in Table 7 are also situated under relatively high clay embankments, and, to make matters worse, they are pipe-arches. These culverts, which are east of Galata, Montana, on U.S. Route 2, were found late in 1963, after the fifty-five project culverts had already been selected and were not studied as intensively as the other cracked culverts.

Why pipe-arches were used at these sites, where the heights of cover are approximately fifteen and twenty feet, is a question that was never fully explored. Be that as it may, the observed heights of cover are, by current standards, excessive. At each of the two sites, the clay backfill material was obviously unable to furnish enough lateral support to permit the culverts to carry the heavy embankment loads without structural distress.

The need for greater care in the design and construction of pipe-arch installations is amply demonstrated by the observed cases of cracked corner plates in Montana. The need has, in fact, become apparent to engineers throughout the country, to the extent that design procedures have been tightened up considerably during the past two years.

The new 1967 "Handbook of Steel Drainage and Highway Construction Products" (10) does not provide "height of cover" tables for the routine selection of structural plate pipe-arches. It does recommend a design procedure which tends to discourage superficial "cook-book" design by unqualified personnel and focuses particular attention on the need for superior back-fill support in the corner regions. The same general trend is apparent in the 1966 structural design criteria of the Bureau of Public Roads (11) and in the latest revision (effective August 1, 1967) of Standard Drawing 60-03 of the Montana Highway Commission.

The revised Montana standard replaces a detailed pipe-arch gage table with a set of more general design guide-lines that are in harmony with the 1966 BPR recommendations and which tend to insure that each pipe-arch design will receive some individual attention from a qualified designer.

For pipe-arches of the size used at the Galata sites, the revised standards now require a "special design" if the height of cover is to exceed nine or ten feet. The revised standards, coupled with improved inspection and construction procedures, will undoubtedly result in a marked reduction in the prevalence of structural distress in pipe-arches in Montana.

A different and highly significant facet of the cracked plate problem in Montana is that the local highway engineers and maintenance personnel contacted were, almost without exception, ignorant of the existence of cracked plates in affected culverts until the researchers brought it to their attention.

As mentioned earlier, cracked plates are usually so inconspicuous that an inspector is likely to overlook them unless he goes into each culvert and conscientiously searches for them. However, after acquiring some experience, the researchers found that they could usually predict, on the basis of outward appearances, whether or not a particular pipe-arch had cracked corner plates. When the corner seam is cracked, the wall between the corner and the crown usually has a moderately sagged or "bowed in" appearance that is readily apparent to an inspector looking straight through the culvert, along the affected side, from a station outside the culvert. In general, any pipe-arch which is sufficiently out of shape so that the distortion is readily apparent from a cursory visual inspection, should be suspected of having cracked plates.

MOMENT STRENGTH OF CULVERT SEAMS

It was apparent, by inspection, that excessive bending or flexing was the immediate cause of the cracked plates observed at longitudinal seams in the culverts discussed in the preceding section of the report.

Attempts to determine the magnitude of the bending moments required to produce the observed damage revealed that there was very little published information on the moment strength of culvert seams. The most useful source of information that could be found was the Michigan Engineering Experiment Station Bulletin 109, by Huber and Childs (12), which was published

in 1951. This bulletin did not give moment capacities directly, but it did provide numerical load and deflection data, from four different series of strength tests, which were analyzed by research project personnel to determine failure bending moments.

The information provided in Bulletin 109 that was used in this investigation pertains mainly to the single bolted sections of Michigan tests three, four, five and six. However, some reference will be made to the tests on plain sections for comparison purposes.

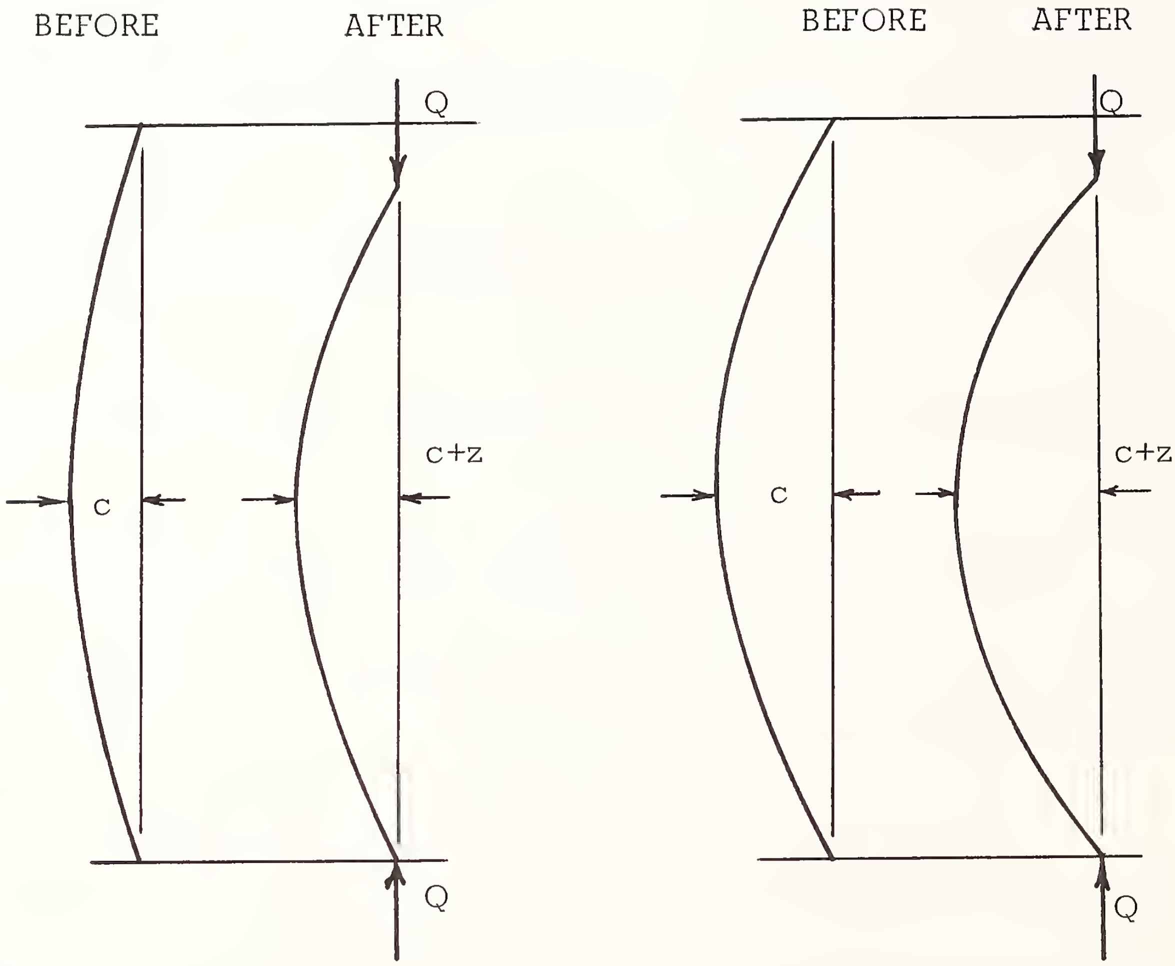
Test three consisted of a column test on sections having a 150-inch radius. The only difference in test four was that 30-inch radius sections were tested (see Figure 46).

Tests five and six were simple beam tests where the specimens were supported at both ends and subjected to a downward force at the center. Test five consisted of 150-inch radius sections while test six had 50-inch radius sections (see Figure 47).

It may be seen, from Figure 46, that the moments developed at failure for tests three and four, M_{max}, are equal to the ultimate load, Q, times (c+z).

Table 8 is a tabulated summary of the analysis of data for tests three and four.

Table 9 is a tabulated summary of the analysis of the data for tests five and six. The maximum moments for tests five and six are equal to

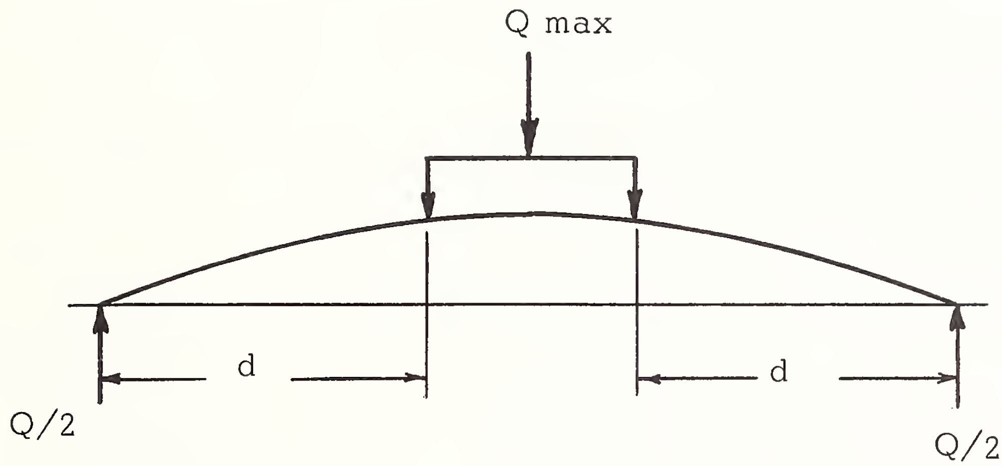


TEST 3
150" Radius Plates

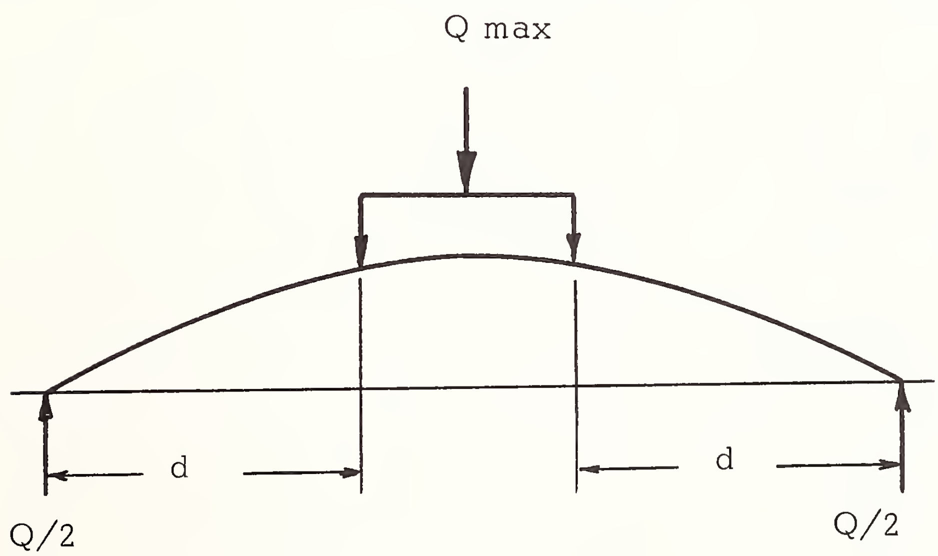
TEST 4
30" Radius Plates

FIGURE 46. STANDARD STRUCTURAL CULVERT PLATES TESTED AS COLUMNS

The sketches show the culvert sections before testing and the deflections at failure for tests three and four in Bulletin 109. z is the horizontal deflection corresponding to the peak load, Q.



TEST 5
150" Radius



TEST 6
50" Radius

FIGURE 47. CULVERT PLATES TESTED AS SIMPLE BEAMS

The sketch shows culvert sections as loaded in the simple beam tests, numbers five and six, in Bulletin 109.

TABLE 8 SUMMARY OF ANALYSIS OF DATA FOR COLUMN TESTS

TEST	GAGE & BOLTED (B) OR PLAIN (P)	Q ULT. LOAD, KIPS	P ULT. LOAD, KIPS PER INCH	c INITIAL MOM. ARM. INCHES	z HORZ. DEF. AT PEAK LOAD, INCHES	x FINAL MOM. ARM, INCHES	Mmax IN-KIPS PER IN. OR FT-KIPS PER FT.	AREA IN^2 PER IN.	$\frac{P}{A}$ KSI
3	1 B	52.3	2.38	2.29	1.42	3.71	8.8	.3432	6.9
	P	79.7	3.62	2.29	0.83	3.12	11.3		
	7 B	42.8	1.95	2.29	1.00	3.29	6.4	.2283	8.6
	P	48.6	2.21	2.29	0.94	3.23	7.1		
	12 B	28.2	1.28	2.29	1.04	3.33	4.3	.1297	9.8
	P	28.0	1.27	2.29	0.81	3.10	3.9		
4	1 B	21.0	0.955	11.05	1.16	12.21	11.7	.3432	2.8
	P	22.0	1.00	11.05	1.09	12.14	12.2		
	7 B	13.0	0.591	11.05	1.41	12.46	7.4	.2283	2.6
	P	12.0	0.545	11.05	0.98	12.03	6.6		
	12 B	7.0	0.318	11.05	0.93	11.98	3.8	.1297	2.4
	P	5.5	0.250	11.05	1.19	12.24	3.1		

TABLE 9 SUMMARY OF ANALYSIS OF DATA FOR SIMPLE BEAM TESTS

TESTS	GAGE & BOLTED (B) OR PLAIN (P)	Q ULT. LOAD, KIPS	P KIPS PER INCH	d AVE. ULT. MOMENT ARM, INCHES	$\frac{Pd}{2}$ MAX. MOMENT IN-KIPS PER INCH
5	1 B	19.0	.864	24.25	10.5
	P	18.9	.860	24.25	10.4
	7 B	11.9	.541	24.25	6.6
	P	11.5	.523	24.25	6.3
	12 B	6.8	.309	24.25	3.7
	P	6.1	.277	24.25	3.4
6	1 B	18.0	.818	23.75	9.7
	P	22.0	1.000	23.75	11.9
	7 B	12.0	.546	23.75	6.5
	P	13.8	.627	23.75	7.4
	12 B	6.9	.313	23.75	3.7
	P	7.6	.345	23.75	4.1

one-half the ultimate load times the distance, d, at the time of failure (see Figure 47).

From the values in Tables 8 and 9, it can be seen that the bolted sections developed, for all practical purposes, the full moment capacity of the unbolted plates.

Also of interest is that the plates of tests three and four, which were under considerable direct compression, P/A, during the bending, resisted bending moments of approximately the same magnitude as the plates of tests five and six, which were subjected to negligible direct compression.

Another pertinent fact about the Michigan tests is that cracks developed at the sides of the bolt-holes and radiated longitudinally outward toward the adjacent bolt holes, in typical bending failures of bolted seams. Cracks of this sort are clearly visible on pictures of typical failures which are shown on page 30 of Bulletin 109. On the basis of this evidence, it is concluded that cracking of the corrugated structural plates, at bolt holes, is a customary or typical mode of failure by bending, and that the observed cases of cracked plates in Montana are typical bending failures and not freak occurrences attributable to unusually brittle metal or any other rare factor.

The failure moments, for the bolted seams of Tables 8 and 9, are shown graphically in Figure 48. The plotted points show a highly consistent pattern which conforms well to the straight-line interpretation shown.

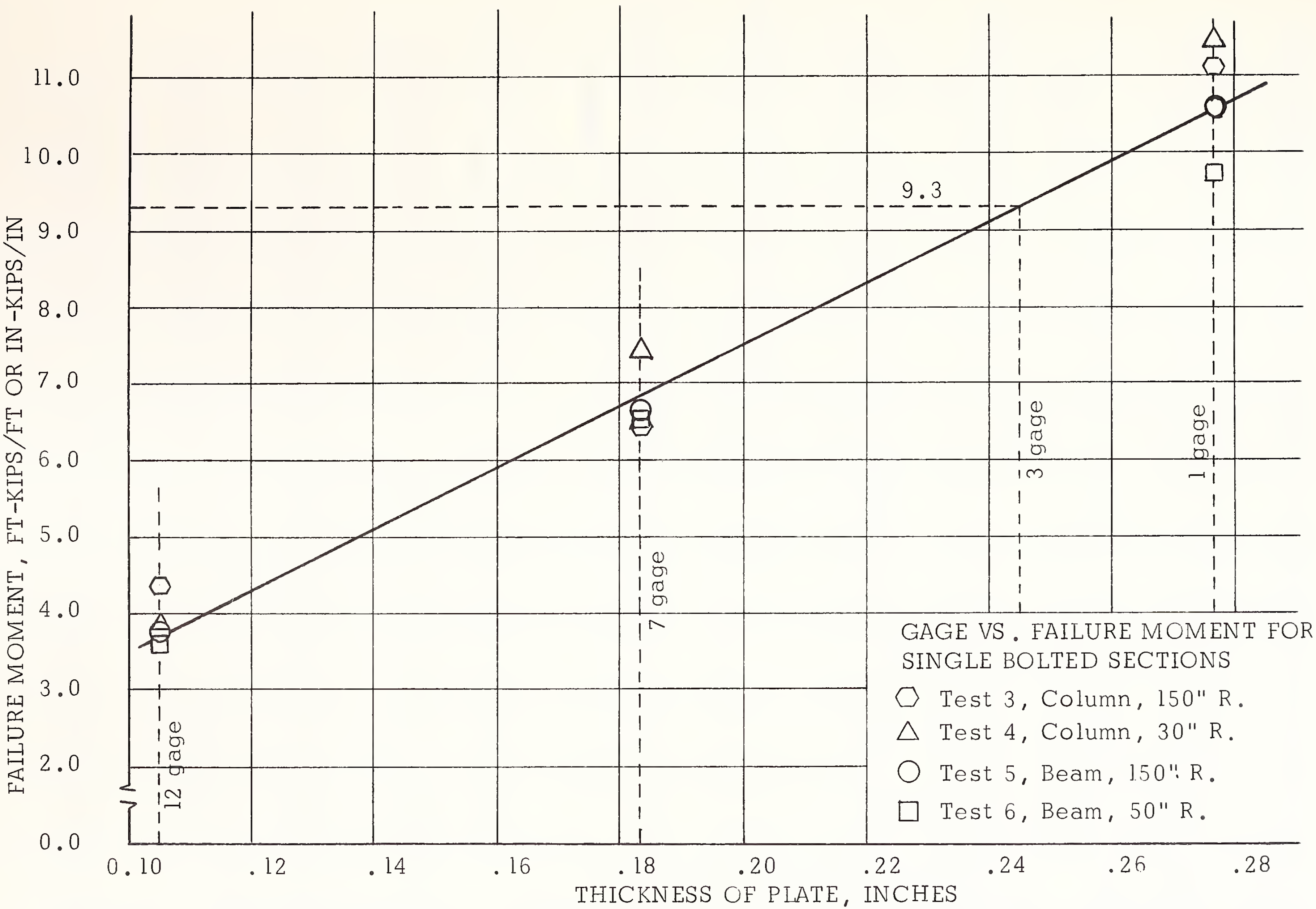


FIGURE 48. FAILURE MOMENTS FOR BOLTED STANDARD STRUCTURAL PLATE CULVERT SEAMS, AS CALCULATED FROM DATA GIVEN ON TEST SERIES 3, 4, 5 and 6 IN THE MICHIGAN ENGINEERING EXPERIMENT STATION BULLETIN NO. 109.

The Figure may be used to estimate the moment strength of structural plate seams in any gage between 12 and 1. For example, the moment strength of a single bolted seam constructed of 3-gage plates (0.245 inches thick) is approximately 9.3 foot-kips per foot, according to the graph.

From the example given above, one might assume that a bending moment near 9 foot-kips per foot of seam was required to produce the cracked corner seam in the 3-gage plates of project culvert No. 1 near Emigrant. Similarly, the bending moments responsible for the cracked plates in the 8-gage and 7-gage culverts of Table 7 would be estimated as approximately 6 foot-kips per foot and 7 foot-kips per foot, respectively. There is, however, an element of uncertainity in these estimations because of minor differences in joint details between the affected culverts and the Michigan test sections which were typical of structural plate seams at the time of the Michigan tests.

The Michigan test sections were fabricated using bolts and washers of the preferred orientation type which provided a large bearing area with the corrugated plates. Currently, washers are no longer used and the nuts and bolt-heads have "spherical" bearing surfaces which bear primarily on the edges only of the bolt holes.

The writer does not question the overall superiority of the modern style bolts, but he does suspect that they provide joints that have less ultimate bending strength than the older joints, carefully fabricated with

"form-fitting" bolts and washers, on which Figure 48 is based. This suspicion has not been dispelled by the very limited amount of unpublished bending test data, for modern-type joints, which the writer has seen.

For persons who wish to estimate the ultimate moment strength of structural plate culvert seams, and make a reasonable allowance for the uncertainties mentioned above, it is recommended that the ultimate moment capacities be taken as seventy-five percent of the values obtained from Figure 48. On this basis, the moment capacity of a single-bolted 3-gage seam would be conservatively estimated at 7 foot-kips per foot, and of a 7-gage seam as 5 foot-kips per foot.

As a practical matter, there appears to be little need for highly refined estimates of the moment strength of culvert seams. The seams are sufficiently strong to develop far more than the elastic bending strength of the unbolted plates. For example, a bending moment of only 4 foot-kips per foot will produce a maximum flexural stress of approximately 30 ksi in a 3-gage plate.

In general, the cracked plate problem will be far more effectively minimized by paying more attention to installation details, and enforcing specifications, than by obtaining more-refined estimates of the bending strength of culvert seams.

CHAPTER V

CLOSURE

The preceding sections of this report cover a wide range of topics and contain recommendations and conclusions too numerous and diverse to permit a logical recapitulation here. The reader is advised to consult each section for the recommendations and conclusions pertinent to the subject matter of that section.

This closing chapter will be devoted to the general subject of culvert inspection. Without any doubt, one of the most important aspects of the large culvert research activity in Montana is that it has demonstrated repeatedly, albeit as an incidental by-product of the research effort, the value of and the need for periodic, thorough, culvert inspection as a means of discovering unsuspected culvert trouble in time to permit appropriate preventive or corrective maintenance action.

The writer has been informed that the Montana Highway Department is now planning to initiate a statewide periodic large culvert inspection program similar to their bridge inspection program which has been in operation for many years. The writer is convinced that such a program will more than pay for itself by detecting, at an early stage, many problems which would otherwise go undetected until they became serious traffic hazards and/or until major maintenance or replacement cost outlays were required.

The replacement cost of a single large culvert installation may run into the tens of thousands of dollars without even considering the cost, dollarwise and otherwise, of the traffic hazards and delays that usually accompany a culvert failure. Hence, a culvert inspection program can pay for itself if it prevents only an occasional large culvert failure.

Furthermore, a centrally directed culvert inspection program will permit a rapid systematic feedback of pertinent information from the field to design engineers and others who can put it to prompt use in the design and construction of new installations. Also, in the long run, the culvert inspection records should serve as a valuable source of factual data for long-range studies of performance, maintenance, and service lives, of culverts and their appurtenances.

Either with or without a centrally directed culvert inspection program, there should be no lessening of local responsibility for frequent culvert inspection and maintenance by local maintenance personnel. It may be stated, as an axiom, that every culvert on every road should be inspected promptly whenever an unusually heavy flow of water occurs. There is no other way to achieve prompt correction of hazardous conditions that may develop overnight or quicker if a culvert becomes inoperative or if embankment scour produces a "drop-off" that requires immediate correction to remove the traffic accident potential.

Ideally, local maintenance personnel should accompany and assist culvert inspectors from headquarters during the statewide large culvert inspections. This would provide valuable culvert inspection training for local maintenance men to help them identify piping, corrosion, and structural problems which are likely to be overlooked unless the inside of each culvert and the embankment at each end of each culvert, is inspected in a very perceptive and knowledgeable fashion.

Inspectors at every level must be trained to realize that a culvert can not be competently inspected from the highway shoulder or from a station part way down the embankment side-slope. A culvert should be inspected <u>from the inside</u> whenever feasible; or at least <u>from each end</u> when it is not possible or practicable to go inside.

It is felt that the periodic inspection of small culverts should be left entirely up to the local maintenance forces. Otherwise, inspectors from headquarters would have to inspect so many culverts that the inspections would almost surely tend to become hasty and superficial.

If an inspector has too heavy a schedule, the inspections will cease to be careful and deliberate. Much of the value of the inspections will be lost if an inspector feels that he cannot afford to take the time to pull the weeds or tumbleweeds away from around the ends of a culvert, to inspect the embankment for piping holes, or to walk slowly through the culvert and inspect the inside walls at close range.

It is strongly recommended that the statewide large culvert inspections not be limited to culverts on roads maintained by state forces, but that they include, as well, all large culverts on those secondary highways that are maintained by county forces. County maintenance personnel are in need of culvert inspection training and should be urged to accompany the state inspectors. During the course of the research project, the researchers found a disproportionately large share of serious culvert problems on secondary highways maintained by counties. Project culverts nos. 6, 7A, 36 and 37, constitute four examples.

It is suggested that all culverts of four-foot diameter, or larger, be classified as large culverts and included in the statewide culvert inspection program. This is approximately the smallest size that can be inspected <u>from the inside</u> without severe discomfort.

It is further suggested that a complete set of inspection and maintenance records for each culvert be kept in one or more permanent files where the information will be readily available to both headquarters and division personnel.

The planning and executing of the periodic large culvert inspection program will be a major task and there is some doubt as to the feasibility of trying to inspect each culvert annually. Biennial inspection should be sufficient if local maintenance men will, in fact, inspect each culvert whenever an unusually heavy flow of water occurs.

It is recommended that inspection data sheets be made up and partially filled out in advance of the actual field inspections, using as-built plans and construction notes to obtain basic reference data such as date of installation, creek name, highway number, project and station, type and size of culvert, number of pipes, gage or other classification, length, coating, height of cover, type of end bevel or end treatment, cutoff walls, riprap, outlet apron, and channel change information. There is no point in recording vast quantities of information that will never be used, but an effort should be made to get enough basic reference information down on the data sheets so that there will seldom be any need to refer back to the plans or construction notes at a later date.

At the time of the first field inspection, on all roads with milepost markers installed, the mileage station of each culvert should be observed and recorded, perhaps to the nearest 0.05 miles. The mileage station will then become the simplest and most convenient means of identifying the location of any culvert along a given stretch of highway.

For the sake of safety, culvert inspectors should use vehicles equipped with flashing caution lights and they should be prepared to set out temporary warning signs when forced to park at hazaradous locations.

The data sheets of Appendix A, which were devised when the research project was just getting underway and before the researchers had acquired a significant amount of culvert inspection experience, were not particularly

good data sheets, even for the research project, and they would be entirely unsuitable for the proposed statewide large culvert inspection program.

Engineers from the Montana Highway Department will be the persons best qualified to design data sheets that will best meet the needs of the Highway Department. Perhaps they will want some phases of the culvert program to be the same as the corresponding phases of their existing bridge inspection program. In any event, they will be the ones using the data and they will have ideas of their own concerning the data that should be taken and how it should be recorded. However, the experiences of the researchers, as set forth in this report, should be of considerable value to them as an aid in devising the correct data sheets for the proposed program.

The writer's current conception of a satisfactory culvert inspection data sheet is presented in Appendix D of this report. This suggested data sheet reflects the influence of the writer's culvert research experience and it is recommended that Highway Department personnel study it before they design their own data sheets. In other words, the suggested data sheet is offered primarily as a study aid, not as a proposed final field data sheet.

A good data sheet must strike a balance between brevity and thoroughness. A culvert inspector's primary concern should be the culvert and its problems, not the problem of filling up spaces on a long and tedious data sheet. A reasonably brief data sheet that contains plenty of space for

written notes about unanticipated problems is to be preferred over a very lengthy and inflexible data sheet that attempts to anticipate all of the culvert problems that an inspector might encounter.

For culverts with serious problems, it will sometimes be necessary to record additional data and notes on additional sheets of paper. For example, a Schmidt Hammer or punch-hole survey might be made, and the results recorded on a separate sheet. If a kit containing such things as a Schmidt Hammer, punches, hammers, wrenches, vise-grip pliers, safety goggles, and a camera, is kept in the inspector's car, it will be possible to conduct certain special investigations on-the-spot, without the need for a separate trip later.

The inspector's equipment should also include a shovel, geologist's pick, pitchfork (for pitching tumbleweeds, etc.),hip boots or waders, rope for safety lines inside culverts, flash lights, folding rulers, steel tape, level rod, insect repellant, and a first-aid kit.

A decision should be made as to whether or not the inspectors should carry, as part of their routine equipment, an inflatable rubber raft or boat to gain access to the inside of culverts when the water is too high or swift for safe wading. The research project personnel were somewhat handicapped at times because they did not have a boat or a raft.

The suggested data sheet, in Appendix D, contains space for recording culvert height and width measurements. This information will not be of much

value unless the measurements are accurately taken, in a reproducible manner, between permanently marked reference points on the inside walls of the culvert.

On new culverts, the measuring points should be marked and the first set of barrel measurements should be taken before the culvert is backfilled. Another set of measurements should be taken as soon as the embankment is completed. Subsequent measurements, taken as part of the periodic inspection program, will then provide an accurate record of culvert deflection which will serve as a valuable index of structural performance.

Height measurements will not always be feasible in culverts containing a significant amount of sediment or water. Measurements of width only will be sufficient for most such culverts. There will also be times when it will not be feasible for an inspector to attempt to venture inside a culvert to make observations or measurements of any kind. It will be hard to justify the effort required to inspect certain culverts from the inside if they appear to be in good condition when viewed from each end. In this connection, the prospect of some physical discomfort should not be accepted as an excuse for not making a thorough inspection of a culvert. The inspection of many culverts will be of a highly cursory nature unless the inspectors are willing to put up with a considerable amount of physical discomfort.

In the final analysis, the degree of success of any culvert inspection program will depend largely upon the conscientiousness of the inspector.

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LITERATURE CITED

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APPENDIX A

SAMPLE CULVERT SURVEY DATA SHEETS

Sheet 1

Date Sept. 16, 1963
Culvert No. 51
Date Installed 1958

County Lewis and Clark Creek So. Fork Dearborn River
Location Highway 434, NW of Wolf Creek
Project No. S 228(1) Station 756+33
No. Pipes 2 Shape: Circle ___ Arch ___ Ellipse ✓
Diam 10' Gage 10 Approx. Length 160' Bit. Coating No
Cutoff Walls: Inlet No Outlet No
Crown Sag Negligible ___ Some ✓ Considerable ___ Extreme ___
Invert Sag Negligible ___ Some ✓ Considerable ___ Extreme ___
Deformation Sides are somewhat wavy (see pictures)
Riprap None
Sediment in Barrel 3" at most
Visible Corrosion Minor, rust stains on bottom
Visible Abrasion Minor on bottom. Solid to pick
Bolts OK
Debris tree limb at inlet (see pictures)
Channel Approach Looks natural

Inlet Erosion Fill between pipes
Outlet Erosion Some undermining and fill erosion
Visible Evidence of Piping None
Inlet Scour Hole None
Outlet Scour Hole In front of right pipe
Fill Soil Gravelly sandy silt, rocks to 6" diameter
Nat. Soil Rocky silt or gravelly silt, sandy

Remarks

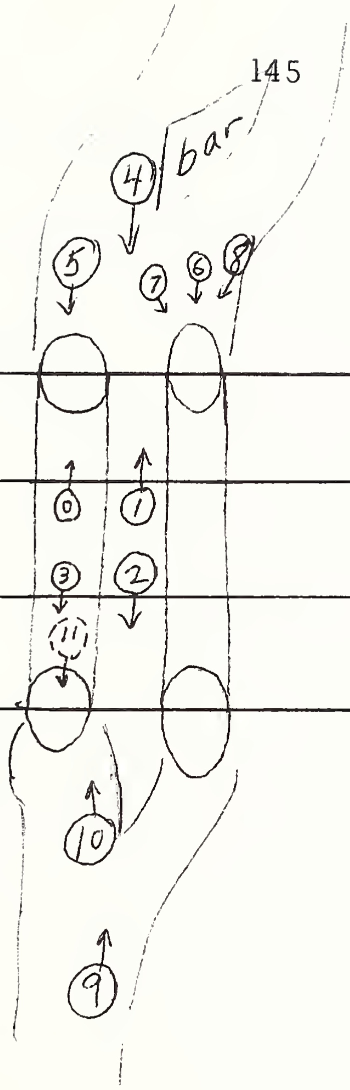
Sheet 2

Date Sept. 16, 1963

Culvert No. 51

SNAPSHOT SURVEY

UPSTREAM



Fill Slope

Roadway

Sheet 3

Date Sept. 16, 1963
Culvert No. 51

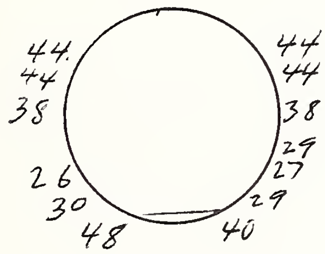
No.	Lens	Speed	Remarks
0	11	125	Upstream Conditions
1	"	"	Inlet & upstream conditions
2	"	"	Downstream
3	"	"	Outlet & downstream
4	"	"	Inlet
5	"	"	Inlet, right barrel
6	"	"	Inlet, left barrel
7	"	"	Undermining & corrosion at inlet
8	"	"	Undermining & fill erosion at inlet
9	"	"	Outlet & outlet channel
10	"	"	Outlet
11	"	"	Downstream from inside right barrel

Sheet 4

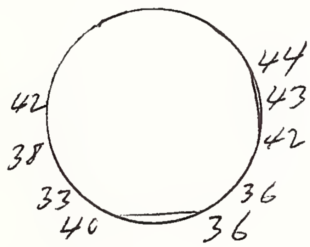
Date *Sept. 16, 1963*
Culvert No. *51*

SCHMIDT HAMMER SURVEY

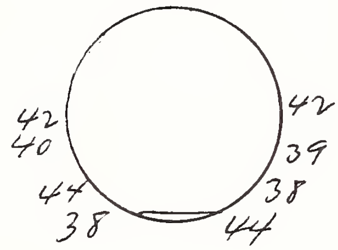
Dist. From ~~Inlet~~
22' from outlet, Right



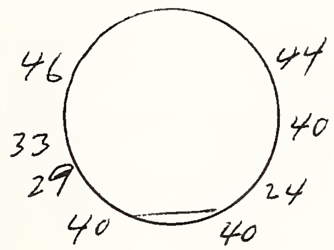
70' from outlet
Right

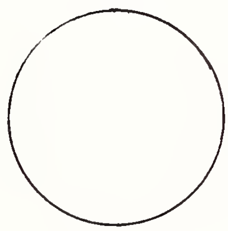


50' from inlet
Right

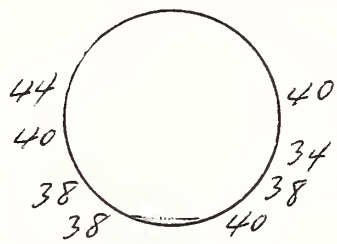


22' from inlet
Right

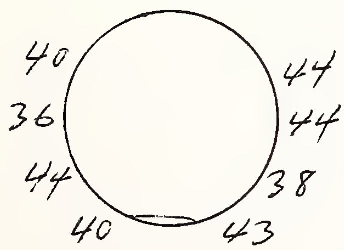




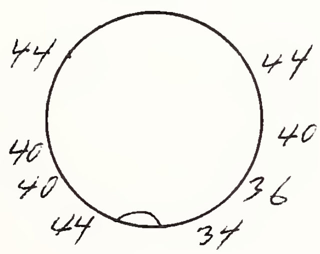
26' from inlet
Left



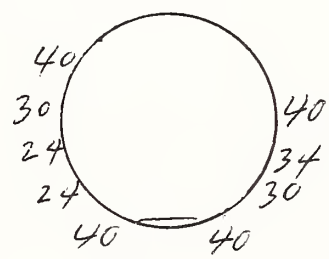
60' from inlet
left



54' from outlet
Left



20' from outlet
Left



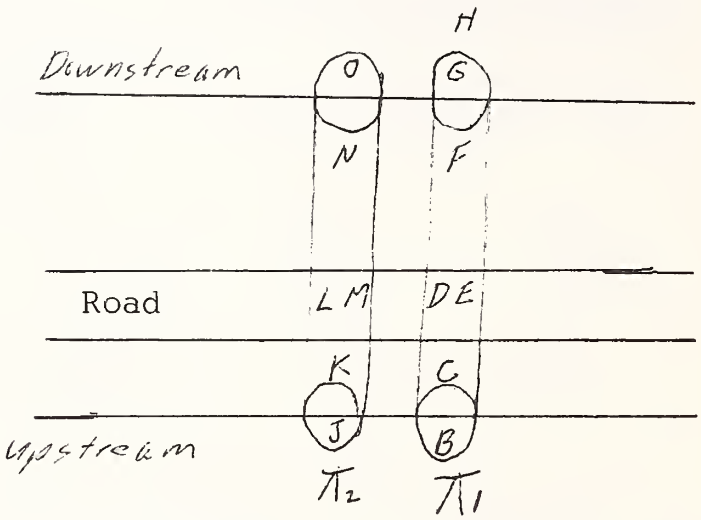
Tentative Indications: *Both barrels appear hollow back to*	
30 feet from outlet; low zones on each side.	
Appears solid for rest of length.	

Sheet 5

Date Sept. 16 1963

Culvert No. 51 I

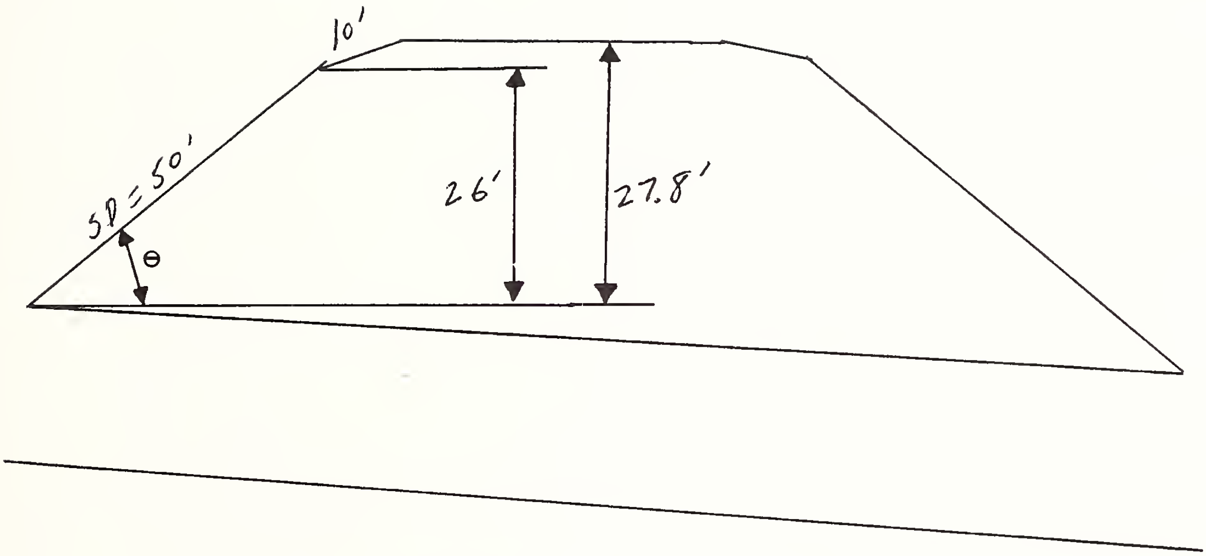
LEVEL DATA SHEET & PLAN SKETCH



POINT	BS	HI	F.S.	ELEV.	REMARKS A
π_1		100.00			
A			4.10		upstream, AB = 167', water surface
B			6.42	93.58	Rt. inlet invert
C			-3.50		Rt inlet crown
D			-2.62		Rt middle Crown
E			7.35	92.65	Rt middle invert
F			-2.32		Rt outlet crown
G			7.85	92.15	Rt outlet invert
H			9.30		Rt outlet scour hole, GH = 10'
I			8.85		Downstream water surface, GI = 150'
J			6.31	93.69	Left inlet invert
K			-3.78	103.78	Left inlet Crown, Turning pt.
π_2		98.57			
K			-5.21		" " " " "
L			-4.42		Lt middle crown
M			5.56		Lt middle invert
N			-3.88		Lt outlet crown
O			6.62		Lt outlet invert

Sheet 6

Date Sept 16, 1963
Culvert No. 51



SIN Θ = ____________

TAN B = ____________

BARREL MEASUREMENTS: Right Left

	INLET	MIDDLE	OUTLET	Inlet	Mid	Outlet
HEIGHT	10'-5"	9'-10½"	10'-3"	10'-6"	10'-0"	10'-3"
WIDTH	9'-9"	10'-2½"	9'-10"	9'-8"	10'-1"	9'-9½"
WATER DEPTH	0.3'	0.5'	0.4'	0.1'	0.1'	0.1'
Sediment Depth	—	3"	—	—	—	—

REMARKS:

APPENDIX B

SUMMARY OF CULVERT SURVEY FINDINGS FOR THE LARGE CULVERT RESEARCH PROJECT

TABLE B1
CULVERT DESCRIPTION AND LOCATION FOR LARGE CULVERT RESEARCH PROJECT

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
1	3	SPPA	16.58 x 10.08	89 Alt. F 217 (10) 785 + 00	Park	Eightmile	3.5 mi. N. of Emigrant	U. S. Steel
2	10	SPPE	7.5	376, S 187 (2), 2101 + 20	Blaine		13.5 mi. S. of U.S. 2	ARMCO
3	--	RCP	9.0	359, S 167 (6), 121 + 41	Madison	Little Antelope	11.6 mi. S. of Jefferson Island	
4	--	RCP	9.0	359, S 167 (6) 195 + 38	Madison	Antelope	10.0 mi. S. of Jefferson Island	
5	10	SPPE	7.0	395, S 167 (5), 473 + 60	Madison		4.4 mi. S. of Jefferson Island	ARMCO
6	10	SPPE	9.0	359, S 167 (3) 133 + 25	Madison		1.1 mi. S. of Jefferson Island	ARMCO

continued on next page

Table Bl continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
7	10	SPPE	11.0	SSG 156 (1) U1 23 + 60	Silver Bow		Victor Chem. Plant Rd. Near Butte, Nissler Overpass	Republic Steel
7A	7	SPPA	12.67 x 8.08	SSG 156 (1) U1 23 + 60	Silver Bow		Same as 7	ARMCO
8	10	SPPE	8.0	191, F 33 (18) 1731 + 73	Phillips	Duvàl	4.7 mi. S. Last Chance Bar	ARMCO
9	10	SPPE	10.0	191, F 333 (18), 1815 + 45	Phillips		3 mi. S. Last Chance Bar	ARMCO
10	10	SPPE	11.0	93, F 259 (8), 611 + 06	Ravalli	Bass	4 mi. S. Florence	ARMCO

continued on next page

Table B1 continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
11	8	SPPA	12.33 x 7.75	93, F 259 (8), 641 + 79	Ravalli	Larry	3.4 mi. S. Florence	ARMCO
12	8	SPPA	12.67 x 8.08	93, F 259 (8), 743 + 06	Ravalli	Sweeney	1.5 mi. S. Florence	ARMCO
13	10	SPPA	9.33 x 6.25	S 10 (3), 8 + 92	Missoula	Mill	In French-town on Secondary Road	Bethlehem Steel Co.
14	10	SPPE	10.0	316, DF 258 (11), 773 + 89	Carbon	Jack	11.8 mi. S. Bridger	ARMCO
15	8	SPPE	15.0	316, DF 258 (11), 964 + 24	Carbon	Jack	7.8 mi. S. Bridger	ARMCO
16	10	SPPC	7.0	87, F 212 (11), 863 + 69	Big Horn	Sunday (Spotted Horse)	1.5 mi. No. of Lodge Grass	Republic Steel Co.

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Table Bl continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	CreekName	Description of Location	Manufacturer of Culvert Plates
17	10	SPPC	7.0	87, F 212 (11), 433 + 08	Big Horn	Long Otter	9.8 mi. No. of Lodge Grass	Republic Steel Co.
18	10	SPPA	11.42 x 7.25	87, IN 90-9 (5) 489, 735 + 43	Big Horn		1 mi. N. Of Crow Agency	ARMCO
19	10	SPPE	12.0	47, F 46 (4), 928 + 50	Big Horn	Sorrel Horse	10.1 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
20	8	SPPE	12.0	47, F 46 (4) 983 + 58	Big Horn	Mission	9 mi. S. of Jct. U.S. 10 & Mont. 47	Republic Steel Co.
21	10	SPPE	10.0	47, F 46 (4) 1080 + 00	Yellow-stone		7.1 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.

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Table B1 continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
22	10	SPPE	10.0	47, F 46 (4) 1145 + 80	Yellow-stone		5.7 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
23	8	SPPE	10.0	47, F 46 (4) 1194 + 15	Yellow-stone		4.7 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
24	8	SPPE	15.0	94, I 94-7 (1) 233, 444 + 50	Wibaux		1 mi. E of Wibaux	Republic Steel Co.
25	5-8	SPPE	15.0	10, F 158 (8), 768 + 00	Custer	Deep	N.E. Miles City	ARMCO
26	8	SPPE	15.0	10, F 158 (8), 706 + 20	Custer	Dixon	N.E. Miles City	ARMCO

continued on next page

Table B1 continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
27	8	SPPE	12.0	10, F 158 (8) 595 + 45	Custer	Spring	N. E. Miles City	ARMCO
28	8	SPPE	15.0	332, S 45 (4), 1810 + 50	Custer	Lay	About 40 mi. S Miles City	ARMCO
29	8	SPPA	11.83	294, S 14 (8), 299 + 12	Meagher	S. Fork Smith R.	4 mi. E of 89 towards Martinsdale	U.S. Steel
30	10	SPPC	8.0	294, S 14 (8), 645 + 49	Meagher	S. Fork Mussel-shell	10 mi. E of 89 towards Martinsdale	U.S. Steel
31	10	SPPC	10.0	294, S 14 (8), 690 + 50	Meagher	Bozeman Fork of Mussel-shell	11.0 mi. E of 89 towards Martinsdale	U.S. Steel
32	10	SPPE	7.0	S 174 (2), 559 + 00	Wheat-land	Galloway	11.4 mi E of Judith Gap	Republic Steel Co.

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Table B1 continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Porject No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
33	10	SPPE	9.0	S 174 (2), 491 + 50	Wheat-land	West Galloway	10 mi. E of Judith Gap	Republic Steel Co.
34	10	SPPA	8.17 x 5.75	S 174 (2) 424 + 30	Wheat-land	Blake	8.7 mi. E. of Judith Gap	Republic Steel Co.
35	8	SPPA	12.50	236, S 68 (3), 862 + 14	Fergus	Dog	S edge of Suffolk	Republic Steel Co.
36	8	SPPA	12.50 x 7.92	236, S 68 (3), 942 + 43	Fergus	Dog	1 mi. N. of Suffolk	Republic Steel Co.
37	7	SPPA	14.08 x 8.75	236, S 68 (3), 1212 + 33	Fergus	Dog	1 mi. S. of Winifred	Republic Steel Co.
38	10	SPPE	10.0	S 261 (2), 98 + 82	Fergus	S. Fork Big Spring	4 mi. S.E. of Lewis-town	ARMCO

continued on next page

Table B1 continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
39	10	SPPE	10.0	S 19 (1), 179 + 10	Fergus		3 mi. S.E. of Lewis-town	U.S. Steel
40	8	SPPE	10.0	10, F 158 (8) 817 + 25	Custer		1 mi. E. of Deep Cr., N.E. Miles City	ARMCO
41	7	SPPA	15.75 x 9.58	10, F 158 (8), 884 + 24	Custer		2.2 mi. E. of Deep Cr., N.E. Miles City	ARMCO
42	8	SPPC	13.75	254, S 32 (7), 304 + 23	Dawson		5.9 mi. N.W. Jct. 16 & 254	ARMCO
43	7	SPPC	13.0	254, S 32 (7), 368 + 84	Dawson		7.4 mi. N.W. Jct. 16 & 254	ARMCO
44	8	SPPE	12.0	20, F 391 (9), 1007 + 40	Dawson	Sullivan	9 mi. S.W. of Richey	ARMCO

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Table B1 contined

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
45	10	SPPE	7.0	24, F 315 (9), 346 + 35	McCone		.75 mi. S. Spillway of Ft. Peck Dam	Republic Steel Co.
46	10	SPPE	10.0	2, F 84 (21), 1461 + 50	Roose-velt		7.1 mi. W. of Wolf Point	ARMCO
47	10	SPPE	10.0	2, F 84 (21), 1536 + 08	Roose-velt		5.4 mi. W. of Wolf Point	ARMCO
48	10	SPPE	7.0	201, S 361 (8), 796 + 60	Richland		15.7 mi. E. Jct. 13 & 201	ARMCO
49	10	SPPE	10.0	201, S 361 (6), 1812 + 00	Richland	West Charlie	24 mi. W of Highway 16 on 201	ARMCO
50	5	SPPA	16.67 x 10.0	2, F 84 (27), 1406 + 50	Roose-velt		8 mi. E Culvertson on U.S. 2	Republic Steel Co.

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Table Bl continued

Culvert No.	Gage	Type	Size, Feet	Highway No., Project No. and Station	County	Creek Name	Description of Location	Manufacturer of Culvert Plates
51	10	SPPE	10.0	434, S 228 (1), 756 + 33	Lewis & Clark	South Fork Dearborn	on Highway 424	Republic Steel Co.
52	10	SPPE	7.0	S 245 (1), 769 + 65	Hill		2.5 mi S. of Gildford	ARMCO
53	--	RCP	6.0	S 70 (1) 258 + 90	Hill		6.5 mi. S. of Havre	
54	10	SPPE	9.0	376, S 187 (1), 2363 + 95	Blaine	White-bear Coulee	8.1 mi S of U.S. 2 on 376	ARMCO
55	10	SPPA	7.83	376, S 187 (1), 2122 + 72	Blaine		13.1 mi. S. of U.S. 2 on 376	ARMCO

TABLE B2
CAMBERS, SLOPES, OUTLET SCOUR HOLE SIZES AND SEDIMENT DEPTHS FOR CULVERTS OF THE LARGE CULVERT RESEARCH PROJECT, 1963

Culvert No.	Camber* Feet		SLOPES				Outlet Scour Hole Size, Feet (Length x Width x Depth	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
1	0	----	.0114	.0225	.0337	.0468 (3' drop)	50 x 25 x 4	1.0	0	0
2	0	-.20	.0032	.0016	.0087	4.5' hole	40 x 30 x 4.5	0	0	0
3	-.10	-.87	.0133	.0167	.0108	.0035		0	0	0
4	-.10	-.90	.0085	.0086	.0207	Pool	28 x 60 x 4	0	.5	.7
5	0	----	.0247	.0262	.029	.0075 (4' hole)	20 x 30 x 4	0	0	0
6	-.10	----	.0326	.0326	.0239			0	0.3	1.5

continued on next page

* The camber is a measure at the middle of the culvert, of the vertical distance from a straight line between the inlet and outlet, minus indicating the measure is down from the straight line and positive indicating the measure is up from the straight line.

** Taken or calculated from plans or construction notes.

NOTE: This summary pertains to data collected during the summer of 1963. Also, the blanks indicate that not enough data was available to make an entry.

Table B2 continued

Culvert No.	Camber* Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
7	0	----	.0042	.0027	.0036	.004	None	4.8	4.5	4.4
8	0	-.11	.0076	.0084	.0024	7' hole	20 x 20 x 6	0	0	0
9	0	-.32	.0030	.004	.0094	3' hole	20 x 20 x 1	0	.2	0
10	0	-.35	.0208	.0198	.0655	.0435	None	0	0	0
11	0	0	.0208	.0208	.0075	.0068	None	0	0	0
12 Left	0	-.53	.0125	.025	.0318	.009	None	0	.8	1.2
12 Right	0	0	.0125	.026	.0318	.009	None	2.0	2.0	2.0
13	0	+.10	.0175	.004	.0045	Drop to pool	60 x 50 x 4	0	0	0
14 Left	0	----	.0078	.0082	.0035	.0075	None	1.8	1.9	2.0
14 Right	0	-.22	.0078	.0085	.0035	.0075	None	0	.5	.8
15 Left	0	+.07	.0063	.0053	.0018	.0047	None	0	0	.4

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Table B2 continued

Culvert No.	Camber*, Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth	Sediment Depth, Feet		
			Culvert		Steam Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
15 Right	0	0	.0063	.0044	.0018	.0047	None	0	.4	.4
16	0	-.15	.003	.0046	.085	2' drop	20 x 20 x 5	1.0	1.0	0
17	0	-.23	.0128	.0112	.0117	.007	None	0	0	0
18	0	-.25	----	.0102	.07	.0067	None	0	.5	0
19 Left	0	0	0	.0023	.021	.0056	None	1.0	.7	.5
19 Right	0	0	0	.0023	.022	.0056	None	1.2	.7	.5
20 Left	0	0	.0014	.0011	.0067	.0231		0	0	0
20 Right	0	0	.0014	.0008	.0067	.0231		0	0	0
21	-.35	-.44	.0066	.0067	.0142	.0017 (2.1 drop)		0	0	0
22	-.1	-.98	.0013	.0047	.0095	.0074		.7	0	.3
23	-.1	----	.021	.0019	.020	.0211 (1' drop)		.8	1.2	.5

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Table B2 continued

Culvert No.	Camber* Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth)	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
24 Left	0	----	.0088	.0078	.0015	.002	None	.5	.7	1.5
24 Right	0	----	.0088	.0078	.0015	.002	None	.7	.7	1.5
25	-.8	+.19	.0092	.0095	.0128	6' drop		.2	0	0
26 Left	-.5	----	.0069	.006	.0034	.005	None	2.3	2.3	2.0
26 Right	-.5	----	.0069	.009	.0034	.005	None	1.5	1.7	1.4
27	-.9	----	.0087	.008	.018	.01	None (2.5' drop)	1.0	1.0	0
28 Left	-.15	----		.0082	.0069	.0061	100 x 100	4.6	4.7	4.7
28 Right	-.15	----		.0004	.0069	.0061	100 x 100	5.4	5.1	5.1
29	0	-.15	.0025	.001	.015	.007	15 x 20 x .5	1.5	1.3	1.1
30	0	-.23		.013	.005	.004	6 x 10 x 1.5	0	0	0
31	+.2	-.46	.0073	.0051	.019	.01	25 x 20 x 3	1.2	.5	0

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Table B2 continued

Culvert No.	Camber* Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth)	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
32	0	-.24	.024	.024	.0128		50 x 8 x 1	0	0	0
33	0	-.37	.0182	.0076	.016	1.7' hole	2 x 8 x 2	0	.5	0
34	0	-.08	.0072	.0055	.025	.0165	10 x 6 x 1	0	.3	0
35 Left	-.1	-.07		.0013	.016	.0025	3 x 2 x .5	0	.2	.1
35 Right	-.1	-.10		.00	.016	.0025	3 x 2 x .5	0	.1	.2
36 Left	0	----	.0055				None	.5	.7	1.0
36 Right	0	----	.0055				None	2.0	1.0	.5
37 Left	+.05	0		.0053	.014	.01		0	0	0
37 Right	+.05	0		.0061	.014	.01		0	0	0
38 Left	0	-.11	.020	.011	.006	4' drop	40 x 45 x 4	0	0	0
38 Right	0	----	.020	.011	.006		40 x 45 x 4	0	0	0

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Table B2 continued

Culvert No.	Camber*, Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth)	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
39	+.6	-.38	.0167	.013	.003	.0615 (3' drop)	8 x 6 x 3	0	.5	0
40	-.9	0	.0427	.04	.0123	.0053 (3' drop)	30 x 20 x 4	0	0	0
41 Left	-.4	----	.0133	.0078	.013	.0045 (2' drop)	Huge, 2 deep	0	0	0
41 Right	----	+.46	.0133	.014	.013	.0045	Huge, 2 deep	0	0	0
42	----	----		.0152	.0023	.0092	None	0	1.2	1.0
43	-.4	----	0	.0015	.0036	.012		3.0	4.0	3.0
44 Left	----	----	0	0	.004	.0043	None	.2	.2	.2
44 Right	----	----	0	.003	.004	.0043	None	.5	.5	.5
45	0	-.48	.0187	.018	.009	.025	30 x 20 x 5	0	0	0
46	-.25	-.12	.020	.0115	.006	.0006	40 x 20 x 4	0	0	0

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Table B2 continued

Culvert No.	Camber*, Feet		SLOPES				Outlet Scour Hole Size Feet (Length x Width x Depth)	Sediment Depth, Feet		
			Culvert		Stream Bed					
	Initial**	Present	Initial**	Present	Upstr.	Downstr.		Inlet	Middle	Outlet
47	0	-.10	.0154	.0054	.0024	.0013	30 x 20 x 5	0	0	0
48	0	0	.0064	.0074	.028		40 x 20 x 4	.5	.3	0
49	-.25	-.12	.005	.007	.0022	.0156	30 x 30 x 3	0	.3	.1
50	0	----	.004	.0012	.003	.0017	None	1.0	.7	.3
51 Left	0	+.19	.0038	.011	.014	.0067	Minor	0	0	0
51 Right	0	-.21	.0038	.009	.014	.0067 (1.5' hole)	Minor	0	.3	0
52	----	-.27	.0046	.009	.042	.03	40 x 30 x 8	0	.3	0
53	0	----	.0253	.02	.008	.0125	None	0	0	0
54 Left	0	-.21	0	.002	.002	.0034	5 x 10 x .5	0	0	0
54 Right	0	-.28	0	.002	.002	.0034	5 x 10 x .5	0	0	0
55	0	+.17	.0028	.0005	.033	.0016	None	0	0	0

TABLE B3 DEFLECTIONS, FILL HEIGHTS, LENGTHS AND YEAR INSTALLED FOR CULVERTS OF THE LARGE CULVERT RESEARCH PROJECT, 1963-1964

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Width*	Present 1963-1964 Height*	Width*	Apparent % Change Nearest 1% Height*	Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
1	SPPA	10.08	16.58	9.60	16.67	-5	+1	6.5	88	1958
				9.18	17.0	-9	+3			
				9.60	16.33	-5	-2			
2	SPPE	7.88	7.12	7.75	7.25	-2	+2	10.0	104	1958
				7.71	7.29	-2	+2			
				7.84	7.25	-1	+2			
3	RCP	9.00	9.00	9.00		0		24.0	150	1961
				9.00		0				
				9.00		0				
4	RCP	9.00	9.00	9.00		0		17.0	118	1961
				9.00		0				
				9.00		0				

* The top number refers to the inlet, the middle number to the middle and the bottom number to the outlet of the culvert.

** Above top of culvert.

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
5	SPPE	7.35	6.65	7.37	6.54	0	-1	19.0	170	1958
				7.05	6.92	-4	+4			
				7.25	6.62	-1	0			
6	SPPE	9.75	8.25	9.33	8.67	-4	+5	9.5	170	1957
				9.08	8.96	-7	+9			
					8.75		+6			
7	SPPE	11.00	10.33		10.67		+3	22.0	144	1955
					10.83		+5			
					10.67		+3			
7A	SPPA	8.08	12.67					Var.	195	1956
				4.67	13.42	-42	+6			
					12.50		-1			
8	SPPE	8.40	7.60	8.25	7.79	-2	+2	13.8	132	1957
				8.21	7.75	-2	+2			
				8.25	7.79	-2	+2			
9	SPPE	10.50	9.50	10.53	9.54	0	0	21.8	166	1957
				10.29	9.73	-2	+2			
				10.46	9.54	0	0			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
10	SPPE	11.55	10.45	12.00	10.33	+4	-1	2.0	96	1956
				11.50	10.67	0	+2			
				11.66	10.42	+1	0			
11	SPPA	7.75	12.33	7.66	12.33	-1	0	7.1	96	1956
				7.66	12.33	-1	0			
				7.66	12.33	0	0			
12 Left	SPPA	8.08	12.67	8.33	12.79	+3	+1	2.0	80	1956
				8.33	12.79	+3	+1			
				8.33	12.67	+3	0			
12 Right	SPPA	8.08	12.67					2.0	80	
					12.67		0			
13	SPPA	6.25	9.33	6.25	9.33	0	0	6.0	80	1955
				6.17	9.42	-1	+1			
				6.42	9.25	+3	-1			
14 Left	SPPE	10.50	9.50		10.0		+5	13.2	128	1958
					10.0		+5			
					9.55		-1			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
14 Right	SPPE	10.50	9.50	10.60	9.50	+1	0	13.2	128	
				10.50	9.50	0	0			
				10.50	9.60	0	+1			
15 Left	SPPE	15.75	14.25	15.75	14.53	0	+2	7.0	160	1958
				15.45	14.75	-2	+4			
				15.60	14.66	-1	+3			
15 Right	SPPE	15.75	14.25	15.80	14.45	0	+1	7.0	160	
				15.70	14.40	0	+1			
				15.80	14.36	0	+1			
16	SPPC	7.00	7.00	6.83	6.96	-2	0	9.7	100	1956
				6.83	7.08	-2	+1			
				6.92	7.08	-1	+1			
17	SPPC	7.00	7.00	6.92	6.92	-1	-1	10.7	94	1956
				6.93	7.08	-2	+1			
				6.92	7.00	-1	0			
18	SPPA	7.25	11.42	7.00	11.50	-3	+1	5.2	100	1958
				6.86	11.62	-5	+2			
				7.08	11.50	-2	+1			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
19 Left	SPPE	12.60	11.40		11.50		+1	10.7	112	1957
					11.60		+2			
					11.58		+2			
19 Right	SPPE	12.60	11.40		11.58		+2	10.7	112	
					11.83		+4			
					11.66		+2			
20 Left	SPPE	12.60	11.40	12.54	11.62	0	+2	11.5	140	1957
				12.33	11.87	-2	+4			
				12.58	11.71	0	+3			
20 Right	SPPE	12.60	11.40	12.46	11.67	-1	+2	11.5	140	
				12.50	11.71	-1	+3			
				12.54	11.67	0	+2			
21	SPPE	10.50	9.50	10.25	9.67	-2	+2	13.6	136	1957
				10.18	9.83	-3	+4			
				10.50	9.58	0	+1			
22	SPPE	10.50	9.50		10.08		+6	19.2	160	1957
				10.08	10.08	-4	+6			
					9.92		+5			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Width*	Present 1963-1964 Height*	Width*	Apparent % Change Nearest 1% Height*	Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
23	SPPE	10.50	9.50		9.83		+4	30.4	200	1957
					10.33		+8			
					9.66		+2			
24 Left	SPPE	15.75	14.25					10.9	160	1962
24 Right	SPPE	15.75	14.25					10.9	160	
25	SPPE	15.75	14.25	15.54	14.42	-1	+1	33.0	168	1953
				15.47	14.54	-2	+2			
				15.85	14.33	+1	+1			
26 Left	SPPE	15.75	14.25		14.83		+4	10.4	144	1953
					14.92		+5			
					14.58		+2			
26 Right	SPPE	15.75	14.25		14.50		+2	10.4	144	
					15.08		+6			
					15.08		+6			
27	SPPE	12.60	11.40		11.83		+4	56.0	256	1952
					12.42		+9			
					12.00		+5			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	DIMENSIONS, FEET: Apparent Original Width*	DIMENSIONS, FEET: Present 1963-1964 Height*	DIMENSIONS, FEET: Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill** Height, Feet of Cover	Length Feet	Year Installed
28 Left	SPPE	15.75	14.25		14.42		+1	2.6	90	
					14.92		+5			
					14.66		+3			
28 Right	SPPE	15.75	14.25		14.66		+3	2.6	90	
					14.83		+4			
					14.54		+2			
29	SPPA	7.58	11.83		11.83		0	2.0	80	1959
					12.0		+1			
					12.0		+1			
30	SPPC	8.00	8.00	7.94	8.02	-1	0	28.5	150	Pre-1959
				7.28	8.50	-9	+6			
				7.87	8.00	2	0			
31	SPPC	10.00	10.00	9.90	9.67	-1	-3	11.0	96	1959
				9.87	10.11	-1	+1			
				9.87	10.14	-1	+1			
32	SPPE	7.35	6.65	7.37	6.54	0	-1	9.7	108	1956
				7.25	6.68	-1	0			
				7.44	6.42	+1	-3			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
33	SPPE	9.45	8.55	9.50	8.46	+1	-1	6.0	88	1956
				9.42	8.58	0	0			
				9.50	8.21	+1	-4			
34	SPPA	5.75	8.17	5.83	8.12	+1	-1	1.33	56	1956
				5.75	8.08	0	-1			
				5.83	8.17	+1	0			
35 Left	SPPA	7.92	12.50	7.63	12.67	-4	+1	3.8	68	1957
				7.42	12.75	-6	+2			
				7.58	12.67	-4	+1			
35 Right	SPPA	7.92	12.50	7.50	12.71	-5	+2	3.8	68	
				7.42	12.75	-6	+2			
				7.63	12.67	-4	+1			
36 Left	SPPA	7.92	12.50		12.75		+2	5.5	72	1957
					13.00		+4			
					12.75		+2			
36 Right	SPPA	7.92	12.50		12.75		+2	5.5	72	
					13.00		+4			
					12.75		+2			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
37 Left	SPPA	8.75	14.08	8.33	14.33	-5	+2	7.0	88	1957
				7.87	14.67	-10	+4			
				8.29	14.42	-5	+2			
37 Right	SPPA	8.75	14.08	8.33	14.33	-5	+2	7.0	88	
				7.87	14.58	-10	+4			
				8.28	14.42	-5	+2			
38 Left	Sppe	10.50	9.50	10.42	9.67	-1	+2	7.9	100	1958
				10.21	9.83	-3	+3			
				10.33	9.71	-2	+2			
38 Right	SPPE	10.50	9.50		9.58		+1	5.6	100	
					9.66		+2			
					9.50		0			
39	SPPE	10.50	9.50	10.38	9.67	-1	+2	6.0	90	1956
				10.25	9.79	-2	+3			
				10.33	9.83	-2	+3			
40	SPPE	10.50	9.50	10.42	9.67	-1	+2	30.5	190	1953
				9.88	10.25	-6	+8			
				10.50	9.67	0	+2			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
41 Left	SPPA	9.58	15.75		15.77		0	6.5	92	1953
				9.50	16.04	-1	+2			
				10.04	15.71	+5	0			
41 Right	SPPA	9.58	15.75	10.13	15.67	+6	-1	6.5	92	
				9.42	16.04	-1	+2			
				10.00	15.79	+4	0			
42	SPPC	13.75	13.75	13.58	14.18	-1	+3	16.5	142	1955
					14.92		+9			
					14.18		+3			
43	SPPC	13.00	13.00		13.17		+1	7.7	93	1955
					13.33		+3			
					13.17		+1			
44 Left	SPPE	12.60	11.40	12.33	11.67	-2	+2	22.0	156	1959
				11.58	12.58	-8	+10			
					11.58		+2			
44 Right	SPPE	12.60	11.40	12.42	11.67	-3	+2	22.0	156	
				11.58	12.71	-8	+12			
					11.50		+1			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET: Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
45	SPPE	7.35	6.65	7.04	6.87	-4	+3	14.0	102	1952
				6.71	7.25	-9	+9			
				7.00	6.87	-5	+3			
46	SPPE	10.50	9.50	10.46	9.75	0	+3	3.0	100	1956
				10.42	9.71	-1	+2			
				10.58	9.54	+1	0			
47	SPPE	10.50	9.50	10.54	9.67	0	+2	15.2	130	1956
				10.42	9.67	-1	+2			
				10.47	9.62	0	+1			
48	SPPE	7.35	6.65	7.33	6.67	0	0	29.0	156	1956
				7.00	6.91	-5	+4			
				7.33	6.67	0	0			
49	SPPE	10.50	9.50	10.25	9.79	-2	+3	8.0	100	1954
				10.04	10.00	-4	+5			
				10.17	9.75	-3	+3			
50	SPPA	10.00	16.67		16.66		0	4.7	100	1960
					16.83		+1			
					16.75		+1			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	Apparent Original Width*	Present 1963-1964 Height*	Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
51 Left	SPPE	10.50	9.50	10.50	9.67	0	+2	27.8	160	1958
				10.00	10.08	-5	+6			
				10.25	9.79	-2	+3			
51 Right	SPPE	10.50	9.50	10.42	9.75	-1	+3	27.8	160	
				9.88	10.21	-6	+7			
				10.25	9.83	-2	+3			
52	SPPE	7.35	6.65	7.25	6.62	-1	0	21.0	130	1958
				7.04	6.87	-4	+3			
				7.58	6.62	+3	0			
53	RCP	6.00	6.00	6.00	6.00	0	0	34.0	150	1956
				5.50	6.33	-8	+6			
				6.00	6.00	0	0			
54 Left	SPPE	9.45	8.55	9.42	8.63	0	+1	13.5	124	1958
				9.08	8.88	-4	+4			
				9.33	8.71	-1	+2			
54 Right	SPPE	9.45	8.55	9.33	8.71	-1	+2	13.5	124	
				9.08	8.92	-4	+4			
				9.33	8.71	-1	+2			

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Table B3 continued

Culvert No.	Type	DIMENSIONS, FEET Apparent Original Height*	DIMENSIONS, FEET Apparent Original Width*	DIMENSIONS, FEET Present 1963-1964 Height*	DIMENSIONS, FEET Present 1963-1964 Width*	Apparent % Change Nearest 1% Height*	Apparent % Change Nearest 1% Width*	Fill ** Height, Feet of Cover	Length Feet	Year Installed
55	SPPA	5.67	7.83	5.63	7.92	-1	+1	3.0	72	1958
				5.63	7.92	-1	+1			
				5.66	7.92	0	+1			

TABLE B4
SOIL DATA, MAJOR PROBLEMS, AND COMMENTS FOR THE PROJECT CULVERTS

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasti-City Index	AASHO Classifi-cation	Major Problems or Features	Comments
1	Gravelly Sandy Silt	43	12	N.P.	N.P.	A-1-b (0)	Installed high; severe piping and cracked corner plates on left side; incipient collapse; channel de-gradation	Replaced in summer of 1967
2	Sandy Silt						Large scour hole and un-dermined outlet	Little change through July, 1967
3	Sandy Gravelly Silt	20	37	39	17	A-6 (2) A-2-6 (2) Borderline	Reinforced concrete pipe	Little change July, 1967

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
4	Sandy Silt	11		40	0		Reinforced concrete pipe.	Large outlet pool almost silted full in 1967.
5	Sand to Silty Clay						Large outlet scour hole threatened irrigation pipe.	Very heavily riprapped to control scour. Looks good in 1967.
6	Silt, rock flour	0	92	29	4	A-4 (8)	Severe piping, right side. Ends of piping hole covered up.	Looks ok in 1967. No recent high water to aggravate piping.
7	Silty Sand	21	3	30.5	5	A-2-4 (0)	Almost 5 feet depth of coarse sand sediment.	Little change through 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample					Major Problems or Features	Comments
		% Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification		
7A	Rock						Cracked plates; buckled floor; incipient collapse.	Has got worse between 1963 and 1967. Is likely to collapse soon if not strutted.
8	Clay and rotten shale	61	36	67	40	A-7-6 (4)	Large scour hole; undermined; alkali deposits; suspected corrosive soil.	Little change through 1967. No apparent corrosion problem.
9	Clay and rotten shale	14		57	32		Large scour hole; undermined; alkali deposits; severe local corrosion.	Roughly 120 local corrosion perforation counted in 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample					Major Problems or Features	Comments
		% Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification		
10	Boulders and gravelly sand						Corrosive water; corrosion nodules on invert.	Water pH=6.9 in July, 1967. Corrosion does not appear significantly worse in 1967 than it was in 1963.
11	Boulders and sandy gravel						Corrosive water; corrosion nodules on invert.	Water pH=6.7 in July, 1967. Corrosion appears to be about the same as in 1963.
12	Boulders and sandy gravel	.51		N.P.	N.P.		Corrosive water; corrosion nodules on invert. Intermittent sedimentation as riprap dam downstream washes out and gets repaired.	Water pH=6.7 in July 1967. Too much sediment in each barrel in 1967 to observe corrosion.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample					Major Problems or Features	Comments
		% Gravel (+No. 10 Sieve)	% Silt and Clay (-N0. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification		
13	Dirty sandy gravel	65		17	0		Large outlet hole.	Scour hole almost filled by gravel sediment after prolonged spring runoff in 1967.
14	Sandy silt; some gravel						Two feet of sediment in left barrel.	Slump of fill beneath rip-rap caused partial failure in 1964. Not inspected in 1967.
15	Clay						Minor channel change.	Not inspected in 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
16	Silty sand and gravel	77		43	22		Channel change downstream. Large outlet scour hole.	Not inspected in 1967.
17	Sandy silt	0		22	0		Inlet undermined 4 or 5 feet.	Not inspected in 1967.
18	Silty Clay	0	87	33	13	A-6 (9)	Inlet undermined about 6 feet.	Not inspected in 1967.
19	Gravelly sand Silt						Up to one foot of sediment.	Negligible change through 1967.
20	Medium plastic silt						Channel change shortened downstream channel by 800 feet.	Slight outlet channel degradation apparent in June, 1967 (one to two feet).

continued on next page

Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample % Gravel (No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
21	Gravelly Sandy silt						Apparently installed one foot high. Minor channel degradation and outlet undermining.	Little change through June, 1967.
22	Gravelly sand, silt						Minor sediment. Grouted outlet apron.	Negligible change through June, 1967.
23	Gravelly silt						Minor channel degradation.	Negligible change through June, 1967.
24	Rotten shale, sandy						Up to 1.5' sediment; channel change upstream.	Not inspected in 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major problems or Features	Comments
25	Stony sandy Silt						Major channel change and extensive downstream channel degradation. Grouted riprap apron failure. Some corrosion and abrasion.	Surprisingly little change between 1963 and 1967.
26	Gravelly clay	16	63	30	11	A-6 (6)	Channel change; 2 feet of sediment; natural sandstone ditch checks.	Virtually no change bebween 1963 and 1967.
27	Gravelly clay	52		31	13		Channel change; minor channel degradation.	Channel degradation less apparent in 1967 than in 1964.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
28	Sandy clay						Approximately 5 feet of sediment in both barrels.	Not inspected in 1967.
29	Gravelly silt, to clay.	26	61	52	17	A-7-5 (9)	Cracked corner plates on left side.	Looked the same in 1967 as in 1963.
30	Sandy rocky silt						Old culvert under high fill. Vertical deflection equals 9%.	Continued to look good in 1967.
31	Rocky silt	52		25	8		Outlet undermining and scour hole.	Little change between 1963 and 1967.
32	Silty gravel						Minor channel change. Outlet scour hole.	No significant change between 1963 and 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
33	Gravelly silt						Undermined outlet; small scour hole.	Little change between 1963 and 1967, Early suspicion of piping not verified.
34	Gravelly silt	46		30	10		Outlet scour hole; undermining.	Scour hole much enlarged between 1963 and 1967.
35	Silt	2		32	13		Embankment scour between the pipes at the inlet.	Scour between pipes at inlet much accentuated between 1963 and 1967. It provided a vertical drop-off only 2 feet from the edge of the pavement in June of 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
36	Silt						Cracked corner plates in both barrels.	Structural condition same in 1967 as in 1963.
37	Silt	29	41	30	7	A-4 (1)	Cracked corner plate in both barrels.	Structural condition unchanged in 1967. Early suspicion of piping could not be vertified. Scour between pipes at inlet will require maintenance soon.
38	Medium clay	30	54	39	11	A-6 (7)	Very large outlet scour hole; single-size riprap; flood problem; suspected piping in 1963.	Replaced by bridge in summer of 1966; piping never verified.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
39	Rotten sandy shale	22	57	27	10-11	A-4 (4) A-6 (4) Border-line	Outlet scour hole and undermining.	Scour hole slightly larger in 1967 than 1963.
40							Channel change and outlet channel degradation. Grouted riprap apron failure.	Very little change between 1963 and 1967.
41	Gravelly silt						Outlet scour hole; undermining; channel degradation. Grouted riprap apron failure.	Not much change between 1963 and 1967.
42	Low plastic silt to high plastic clay						Large deflection; some corrosion and abrasion. Corrosive soil.	Negligible change since 1963. Corrosion appears to be stabilized.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
43	High plastic silt to sandy silt; highly aklaline.						White alkali deposits; some corrosion.	Little change between 1963 and 1967.
44	Low plasticity clay	0	92	34	12	A-6 (9)	Cracked plates along side seams in both pipes.	General appearance does not indicate additional structural deterioration since 1963, but high water has prevented close inspection.
45	Clay and shale, alkali						Severe localized corrosion; corrosive soil; large scour hole. Has had very high water.	Over 800 local perforations in 1967, but still structurally adequate.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification	Major Problems or Features	Comments
46	Clay	0	85	44	25	A-7-6 (15)	Scour hole; inlet and outlet undermined; early stage piping suspectedin 1963. Channel change.	Little change between 1963 and 1967. Piping not verified.
47	Clay	5	73	42	22	A-7-6 (13)	Outlet scour hole and undermining; early stage piping suspected in 1963. Channel change.	Little change between 1963 and 1967. Piping not verified.
48	Sandy silt		67	30	9	A-4 (6)	Large scour hole; deeply undermined outlet. Has experienced very high water. Early stage piping suspected in 1963.	Negligible change between 1963 and 1967. No piping. Covered gully in sluffed fill looks like piping hole.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample					Major Problems or Features	Comments
		% Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	AASHO Classification		
49	Low plasticity silt		85	30	10	A-4 (8)	Outlet scour hole; suspected early stage piping in 1963.	No change since 1964. No piping. Covered gully fill erosion looks like piping hole right side of outlet.
50	Medium plastic clay						Channel change. early stage piping suspected in 1963.	Piping not verified. Not inspected in 1967.
51	Gravelly sandy silt						Sediment deposits upstream. Some outlet scour and undermining. Inlet scour between pipes.	Minor outlet scour hole of 1963 much enlarged by floor of 1964. little change between 1964 and 1967.

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Table B4 continued

Culvert No.	Field Classification	Embankment Soil Sample: % Gravel (+No. 10 Sieve)	% Silt and Clay (-No. 200 Sieve)	Liquid Limit	Plasticity Index	ASSHO Classification	Major Problems or Features	Comments
52	Sandy, low plastic clay	8	58	27	13	A-6 (6)	Has had very high water; large outlet scour hole and undermining. Early stage piping suspected in 1963.	Piping not verified. Little change between 1963 and 1967.
53	High plastic clay						Severely cracked and distorted reinforced concrete pipe.	Negligible change between 1963 and 1967.
54	Silt	21	41	25	6	A-4 (1)	Piping suspected in 1963.	Piping not verified. Little change between 1963 and 1967.
55	Silt to clay						Piping suspected in 1963.	No piping. No change between 1963 and 1967.

APPENDIX C

PUNCH-HOLE VS. SCHMIDT HAMMER DATA TABULATIONS

TABLE C1 PUNCH-HOLE VS. SCHMIDT HAMMER DATA FOR 10-GAGE PIPE-ARCHES

	REGION READINGS WERE TAKEN								
	WALL			18" RADIUS			FLOOR		
	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	32	34	40	24	38	40	24	28	35
	30	36	40	26	40	40	26	30	38
			41	34	38	44	22	33	
				34	42	44			
				34	40	50			
				30	42				
					40				
					38				
					36				
AVE.	31	35	40	30	39	44	24	30	37

The numbers in the table are Schmidt Hammer readings taken at points where holes were punched to determine the fill condition.

TABLE C2 PUNCH-HOLE VS. SCHMIDT HAMMER DATA FOR 10-GAGE CIRCULAR CULVERTS

READINGS FROM BOTTOM HALF OF CULVERT			
	EMPTY	SOFT	FIRM
	26 READINGS TAKEN	66 READINGS TAKEN	22 READINGS TAKEN
RANGE	25 ± 2	29 ± 4	38 ± 8

Too many Schmidt Hammer readings were taken to list singly; therefore, the number of readings that were taken are noted along with the ranges which include at least 80 percent of the readings.

TABLE C3 PUNCH-HOLE VS. SCHMIDT HAMMER DATA FOR 8-GAGE PIPE-ARCHES

	REGION READINGS WERE TAKEN								
	WALL			18" RADIUS			FLOOR		
	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
		38	43	40	46	50	36	32	40
		35	40	40	46	50	34	34	
		38	40	40	44	50	32	38	
		40	42	40	38	50	38	30	
		42	42	42	48	50	30	30	
		40	42		44	48	34	38	
		38			40	50	34		
		40			45	52	30		
		40			40	48	36		
		42			46	48			
		44			44				
		40			46				
					46				
					44				
					42				
					42				
					42				
AVE.		40	42	40	44	50	33	34	40

The numbers in the table are Schmidt Hammer readings taken at points where holes were punched to determine the fill condition.

TABLE C4 PUNCH-HOLE VS. SCHMIDT HAMMER DATA FOR A 3-GAGE PIPE-ARCH

	REGION READINGS WERE TAKEN								
	WALL			18" RADIUS			FLOOR		
	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	40	40	44	40	46	52	38		44
	44	40	45	40	44	50	42		48
	42	40	48	42	44	48	40		44
	40	44	46	42	42		38		48
	40		46	39	44				
	41		48	42					
			46	40					
AVE.	41	41	46	41	44	50	40		46

The numbers in the table are Schmidt Hammer readings taken at points where holes were punched to determine the fill condition.

APPENDIX D

SUGGESTED CULVERT INSPECTION DATA SHEET

SUGGESTED CULVERT INSPECTION DATA SHEET

Culvert No. ____________ Mileage Station __________ Date Inspected ______
Creek Name ____________ Highway No. ____________ Date Installed ______
Project and Station Number ____
Type Culvert: RCP, CMP, SPPC, SPPE, SPPA, Other ____________________
Manufacturer ____________________ No. of Pipes ________ Size ____________
Length ______________ Gage or Other Classification ____________________
Coating ______________________ Height of Cover ________________________
Upstream Channel Change: None __________ Minor _______ Major __________
Downstream Channel Change: None _________ Minor _______ Major _________
Type End Bevel ____
Type headwall at inlet ____________________ Condition ____________________
Type endwall at outlet ____________________ Condition ____________________
Type outlet Apron _______________________ Condition ____________________
Type outlet riprap __________________ Type inlet riprap ___________________
Type debris barrier ____
Type and amount of debris ____
Describe evidence of differential settlement of pavement above culvert ____
____
Visible evidence of pavement patching: None _____ Some _____ Much ______
Extensive ____
Is culvert near sag point of vertical curve? ______________________________
Embankment erosion: Negligible ________ Rills several inches deep ________
Gullies ______________ Local slumps or slides _______ Other ______________
Embankment soil type ____
Channel sides soil type ____
Channel bed soil type ____
Pull weeds, tumbleweeds, or other debris away from the ends of the culvert and search for piping holes in the embankment. Describe any visible evidence of piping. ____
____
____
____
____
Depth of water in culvert at time of inspection __________________________
Elevation of high water marks ____
Known water level from past floods _____________________ When? ________
Scour at inlet: None ________ Minor _______ Moderate _____ Major ________
Describe ____
Scour at outlet: None _______ Minor _______ Moderate _____ Major ________
Describe ____
____
____

Suggested Culvert Inspection Data Sheet (continued)

Length of undermining at inlet ____________ at outlet ______________
Outlet scour hole size, approximate: Length __________ width __________
depth ____
Does scour hole endanger fence, endwall or other structure? __________
Describe ____
Is outlet channel visibly degraded? _____ How far downstream was channel inspected for vertical waterfalls indicative of channel degration working its way upstream? ____
Type and depth of sediment in culvert ______________________________

Type and location of alkali deposits or stains ______________________

Does soil or water appear to be highly alkaline or polluted? __________
Describe ____

Visible corrosion: None _____ Minor _____ Serious _____ Describe _____
corrosion ____

Are walls solid to geologist's pick? ______________________________
Describe visible abrasion ______________________________________

Crown sag: None ____ Slight __________ Moderate ______ Extreme ______
Invert sag: None _____ Slight _______ Moderate ______ Extreme ______
Other obvious deformation ______________________________________

Are plates cracked at seams? ______________________________________
Describe location and extent of cracked plates or other structural distress
____
____
____

Barrel Measurements at permanently marked measuring points: __________
__________ Inlet ____ Middle ____ Outlet ____________________________
Height ____
Width ____
Describe items that require prompt maintenance ______________________
____
____
____
____
____
____
____

Suggested Culvert Inspection Data Sheet (continued)

Describe items that require additional investigation or special attention in the future ______________________________

Other notes, photographs taken, etc. ______________________________